SUSTech Southern University of Science and Technology

Calibration of measuring equipment

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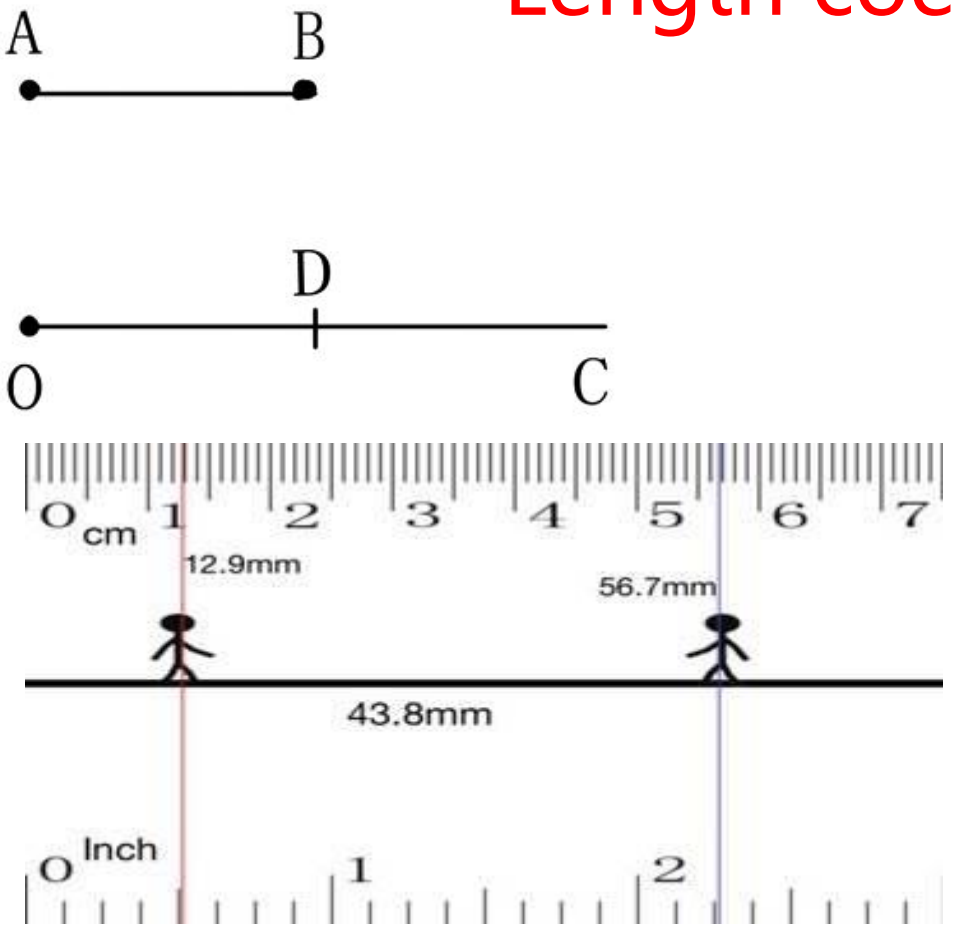
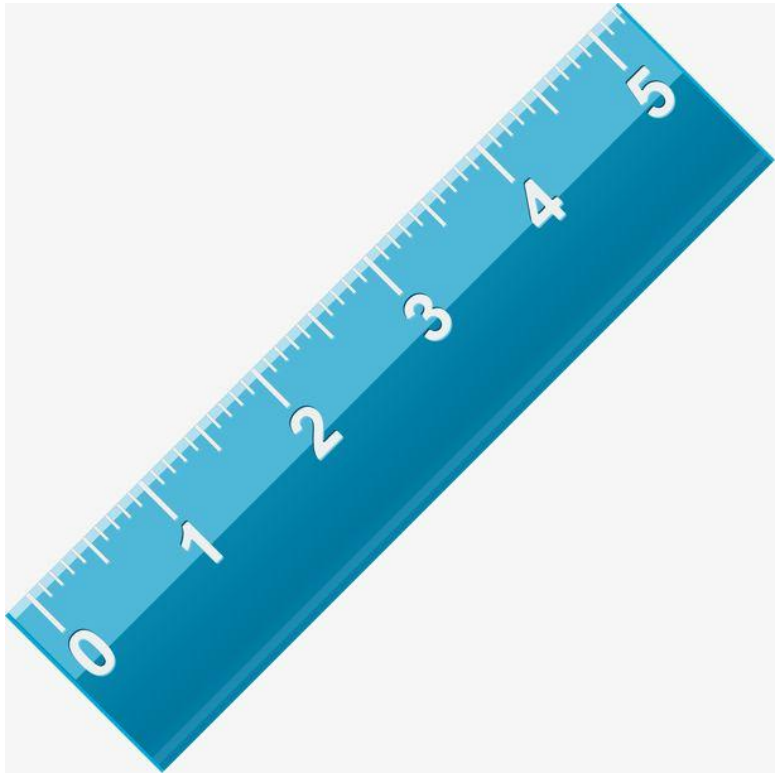
2020.09.16

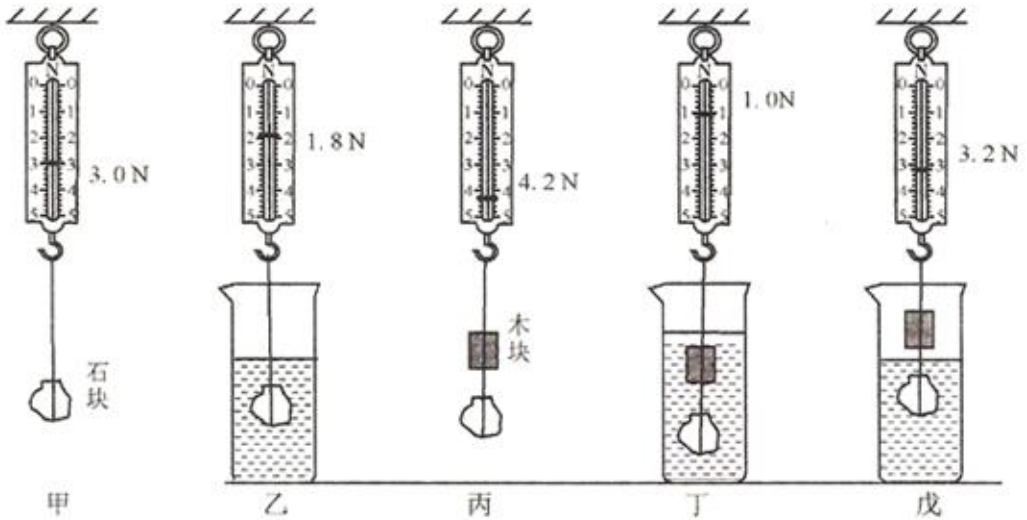
Calibration of Line measurement

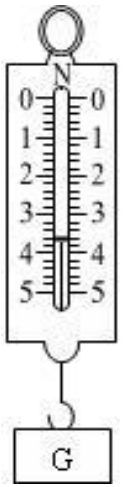
Length coefficient

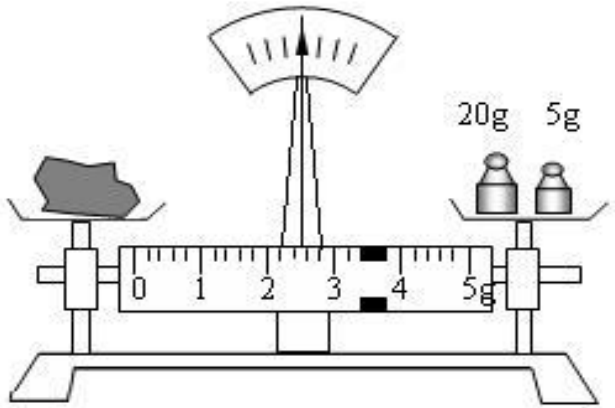


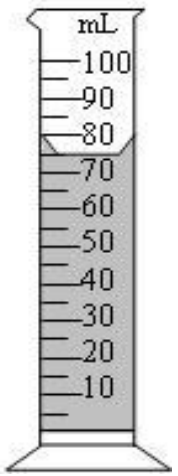


Calibration of Spring dynamometer

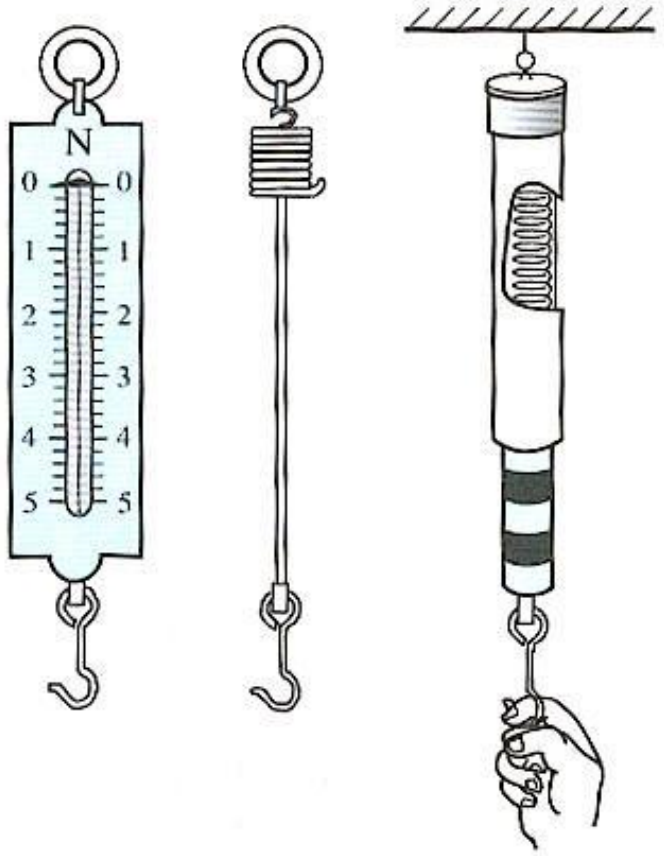




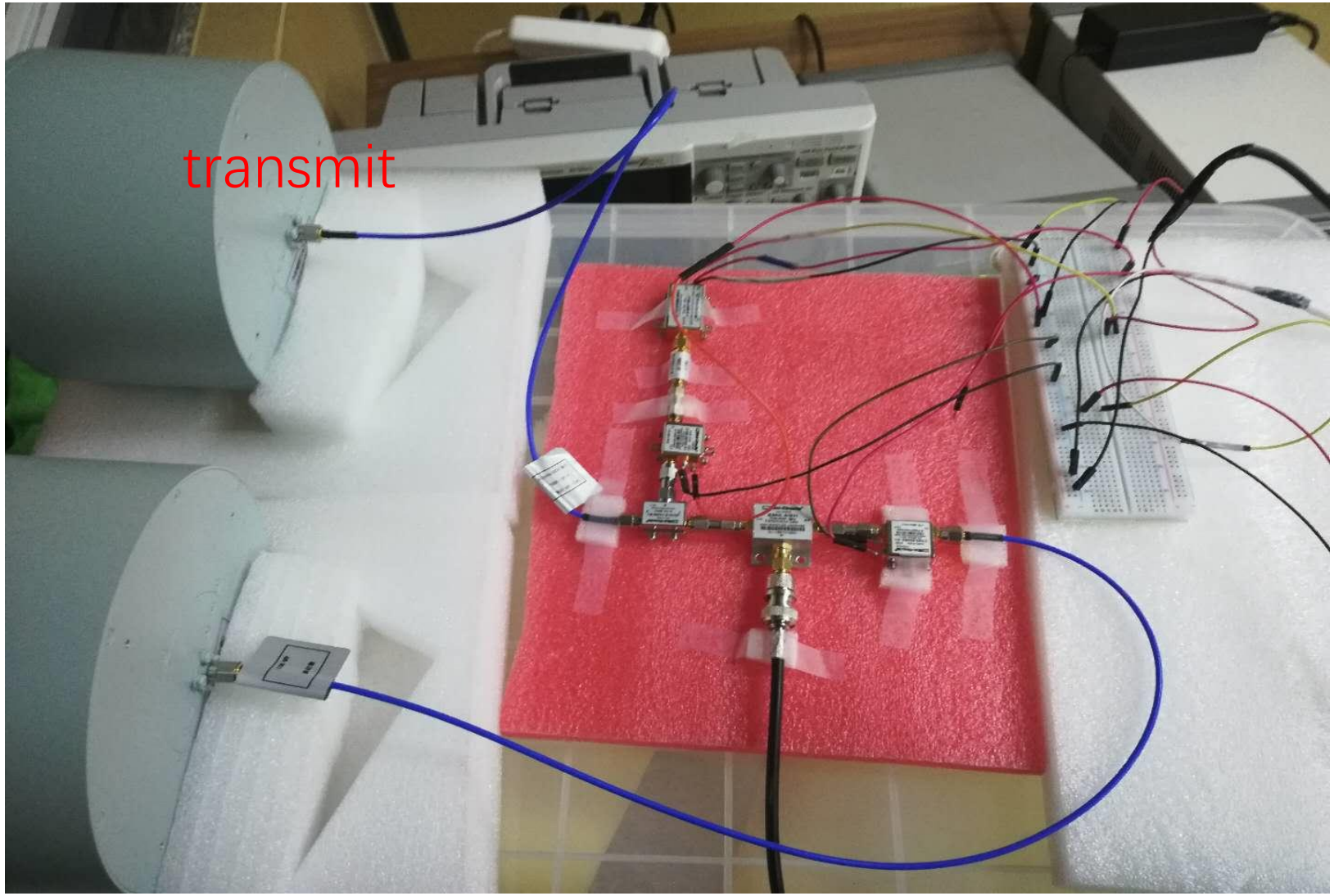




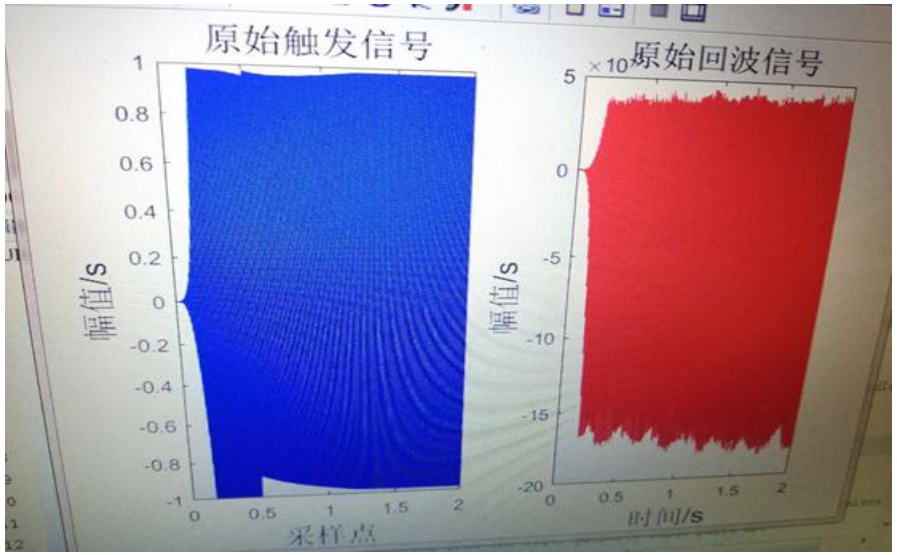
Elastic coefficient

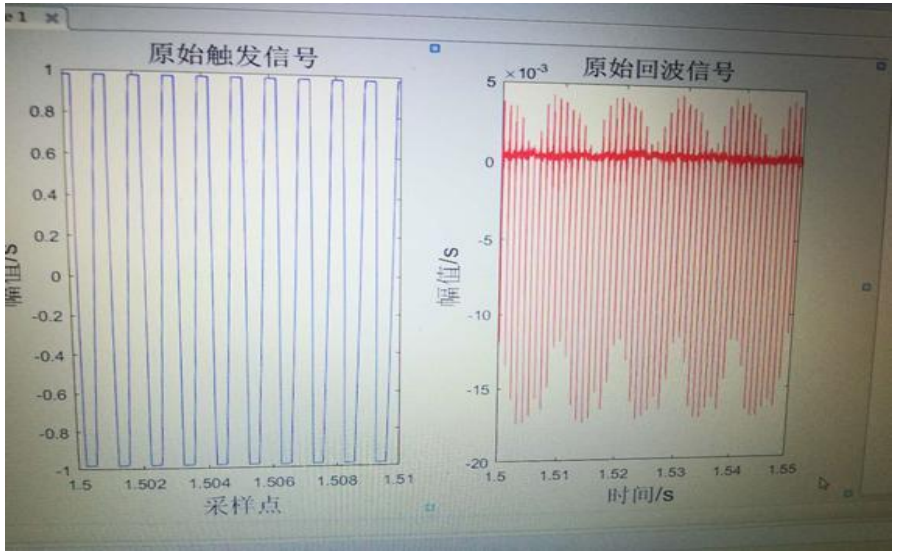


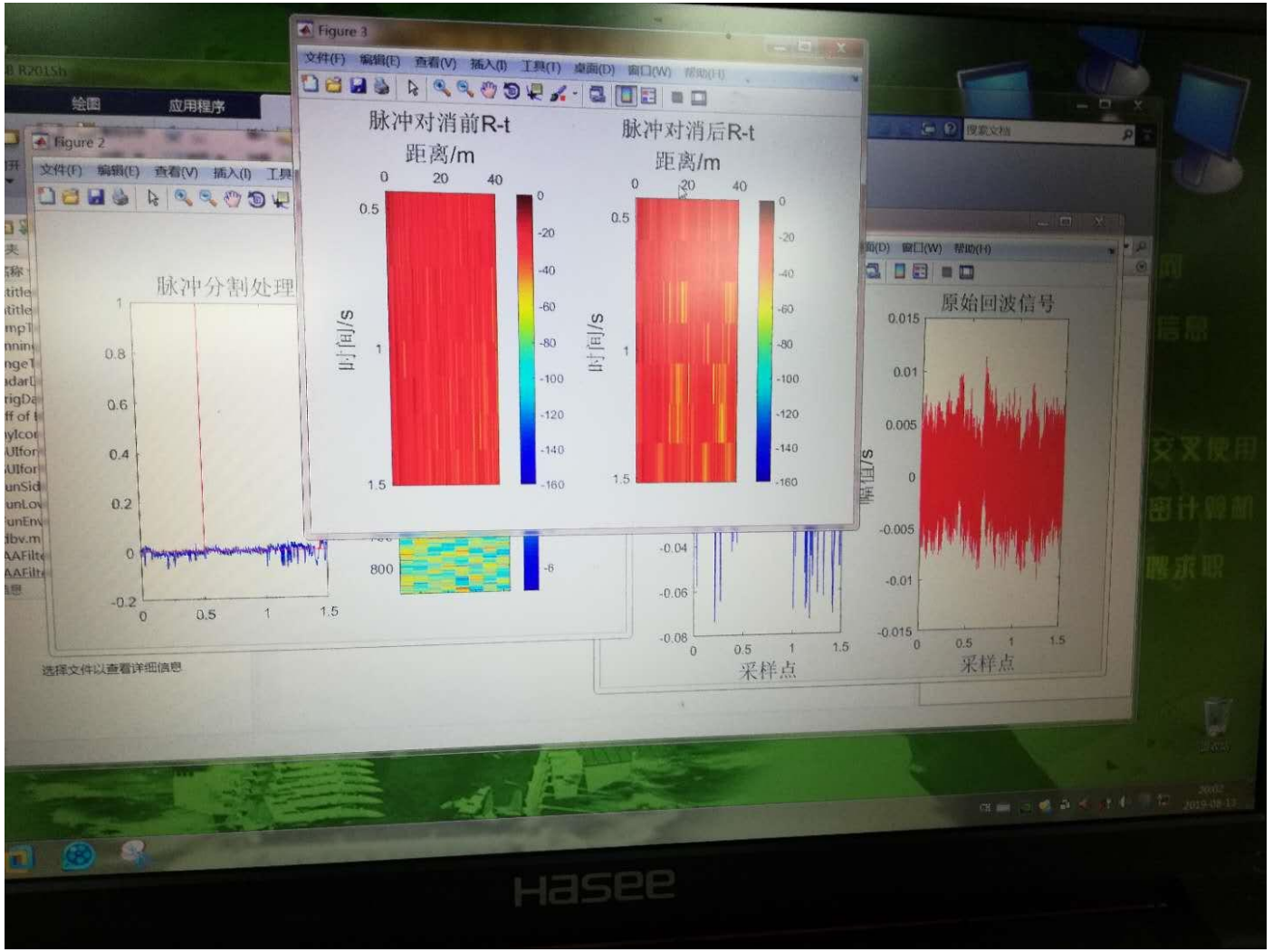
Calibration of radar



Calibration of radar

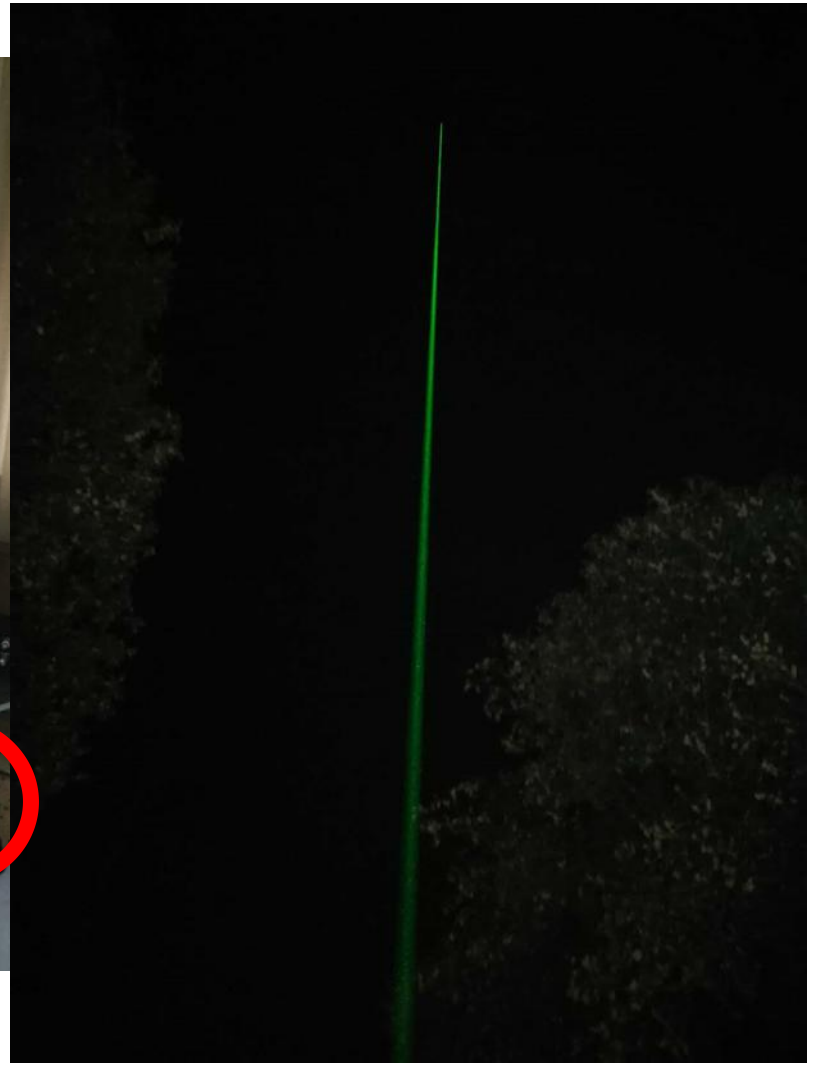


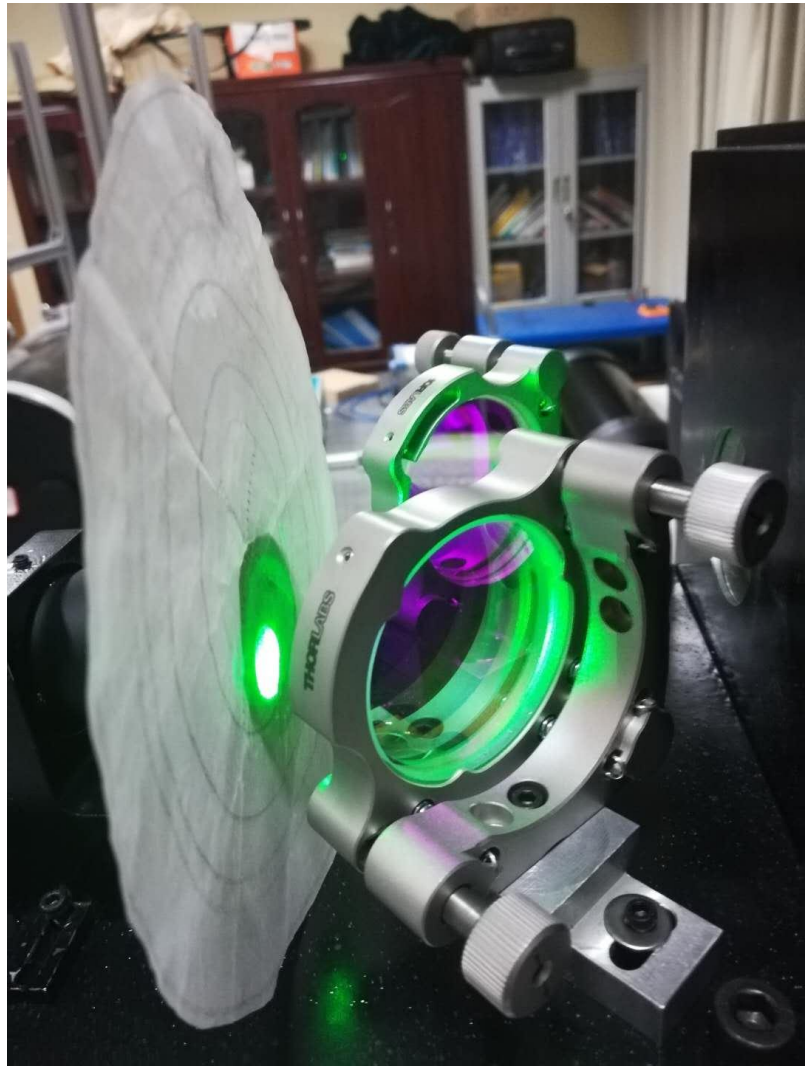




Calibration of lidar

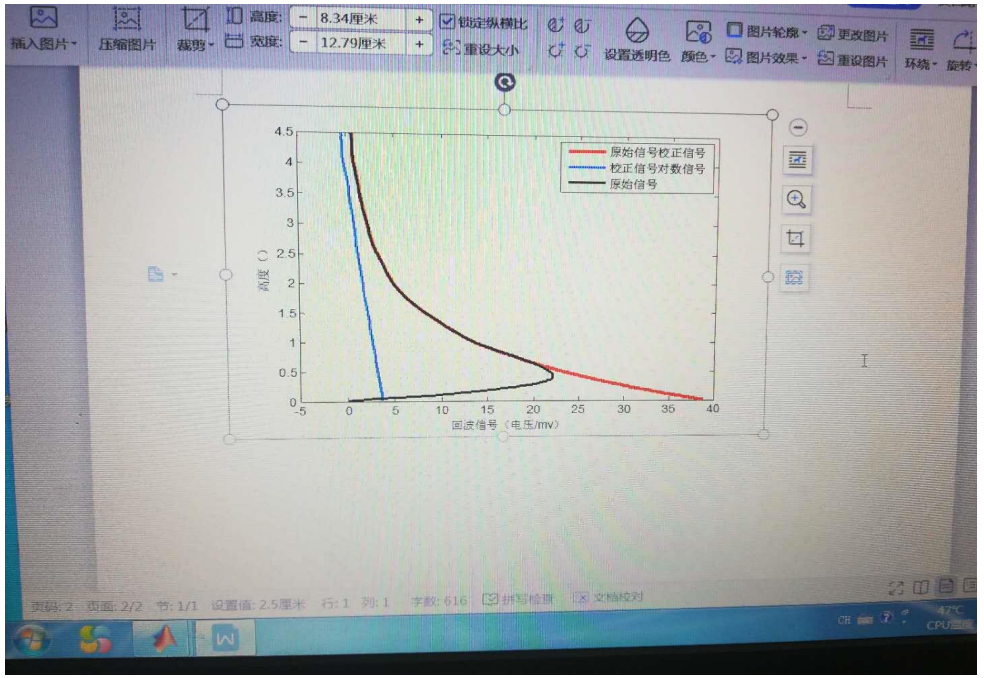
Calibration of lidar





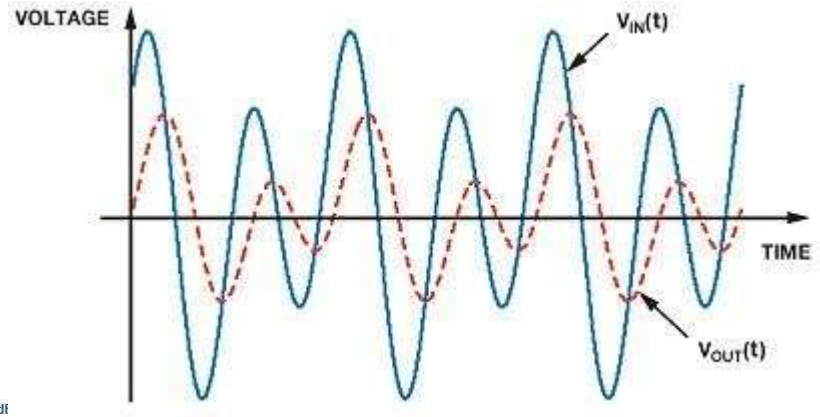
Calibration of lidar

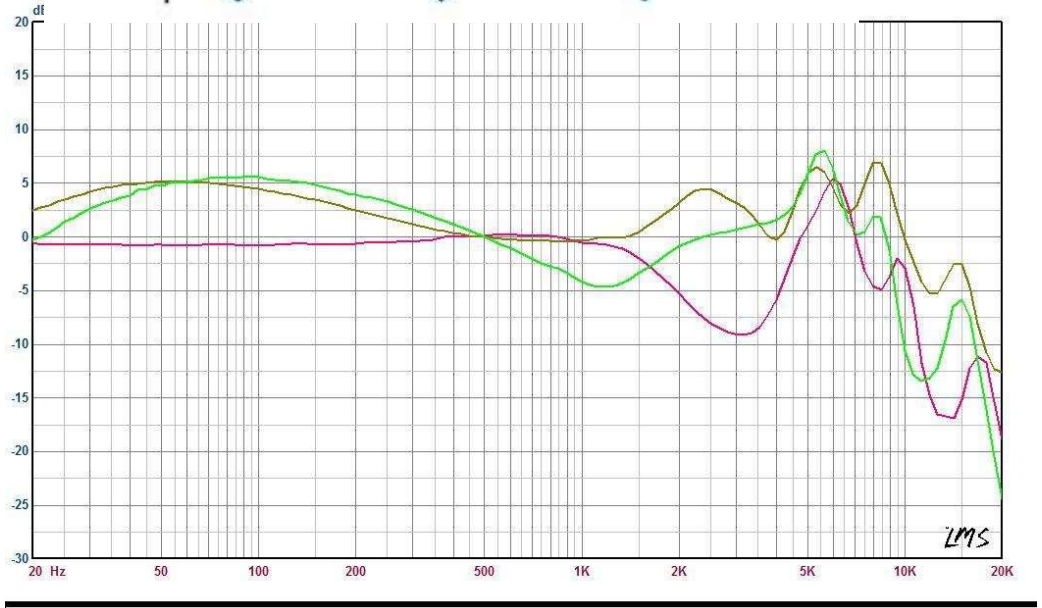
1. 平面波 $\vec{E}(\vec{r}) = Ae^{-i\vec{k}\cdot\vec{r}}$ 等相面（波前）是平面
2. 球面波 $\vec{E}(\vec{r}) = \frac{A}{\vec{r}}e^{-i\vec{k}\cdot\vec{r}}$ 等相面是球面
3. 柱面波 $\vec{E}(\vec{r}) = \frac{A}{\sqrt{\vec{r}}}e^{-i\vec{k}\cdot\vec{r}}$ 等相面为圆柱形
4. 抛物面波 $\vec{E}(\vec{r}) = \frac{A}{z}e^{-i\vec{k}\cdot\vec{z}}e^{-ik\frac{x^2+y^2}{2z}}$ 复杂



Calibration of electric filed measurement

Find the complex transfer function





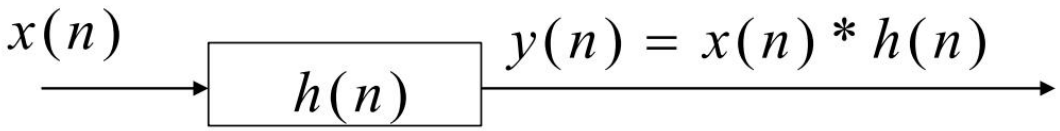
Calibration of electric filed measurement

$$y(n) = S[x(n)]$$
$$= S[\sum_{k=-\infty}^{\infty} x(k)\delta(n-k)]$$
$$= \sum_{k=-\infty}^{\infty} x(k)S[\delta(n-k)]$$
$$= \sum_{k=-\infty}^{\infty} x(k)h(n-k)$$

linearity of the system

Time-invariance of the system

$$y(n) = \sum_{k=-\infty}^{\infty} x(k)h(n-k) = x(n) * h(n)$$



$$Y(\omega) = X(\omega) \cdot H(\omega)$$

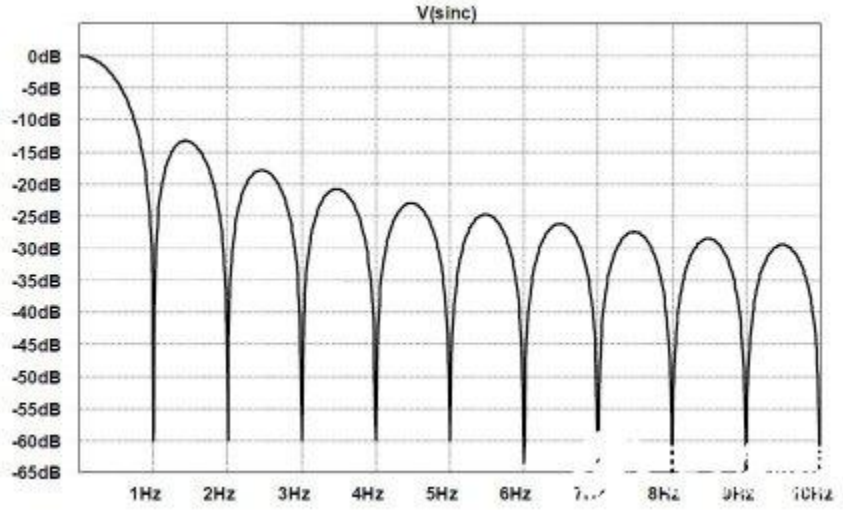
Convolution in the time domain is equal to multiplication in the frequency domain.

Calibration of electric filed measurement

Arase satellite

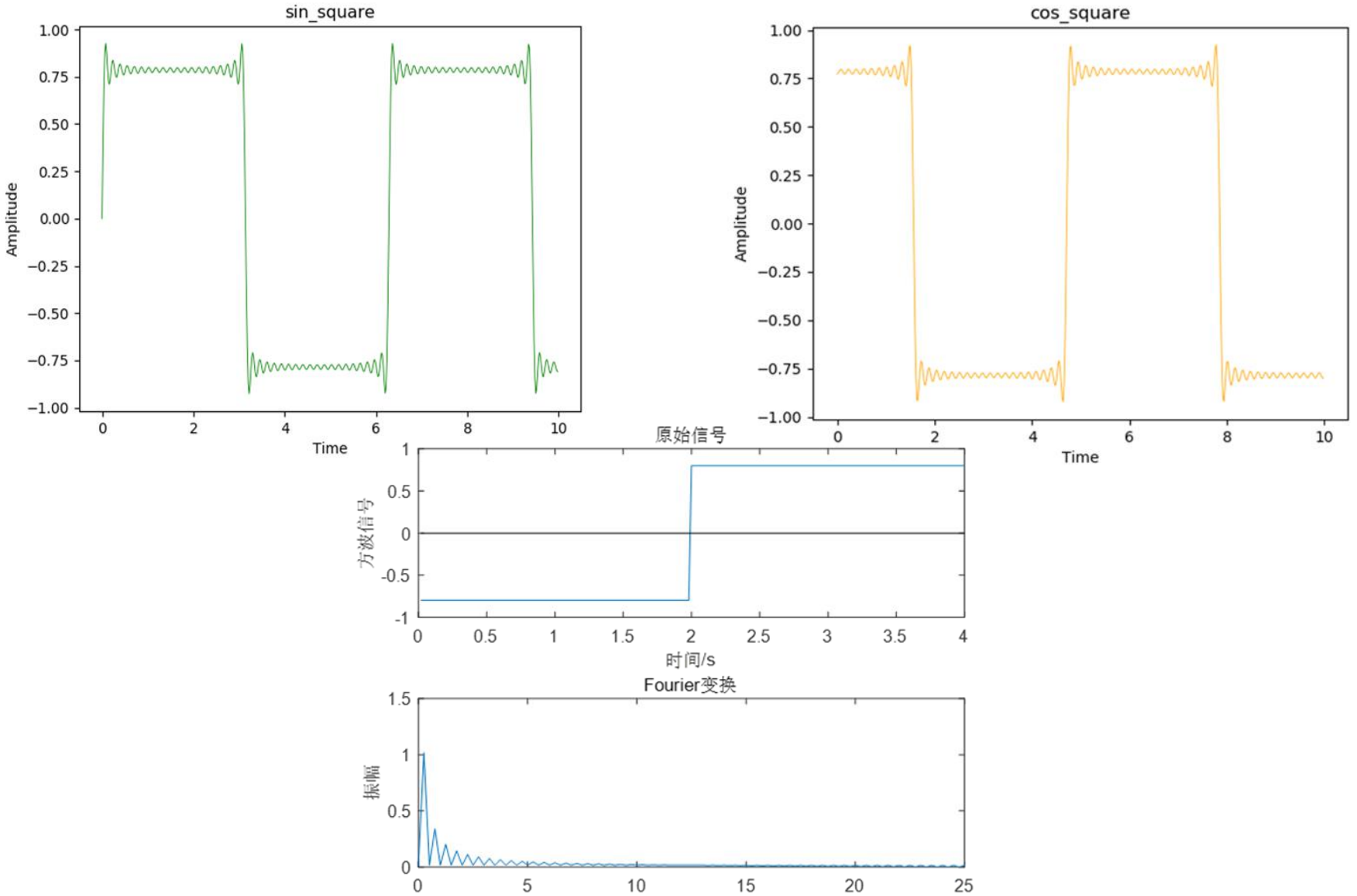
- The SW(software)CAL function is a function of the onboard software of WFC/OFA used for measuring the transfer functions of the receiver and the electric field's antenna impedance.
- Generates a square waveform with an arbitrary frequency as a calibration signal.
- we generate a square wave identical to the calibration signal and calculate it's Fourier transform $G(\omega)$.
- The transfer function of the receiver $H(\omega)$ can be obtained using the following ground processing equation.

$$H(\omega) = G(\omega)/F(\omega)$$



（Shoya Matsuda, et al. 2018） Arase satellite

Calibration of electric filed measurement



Calibration of electric filed measurement

Electric field calibrations of the HFR receiver were performed by applying pure sinewave tones at 1 MHz (baseband), 3.5 MHz, 6.5 MHz, 10.5 MHz, 21.5 MHz, 29.5 MHz , and 38.5 MHz at the preamplifier inputs.

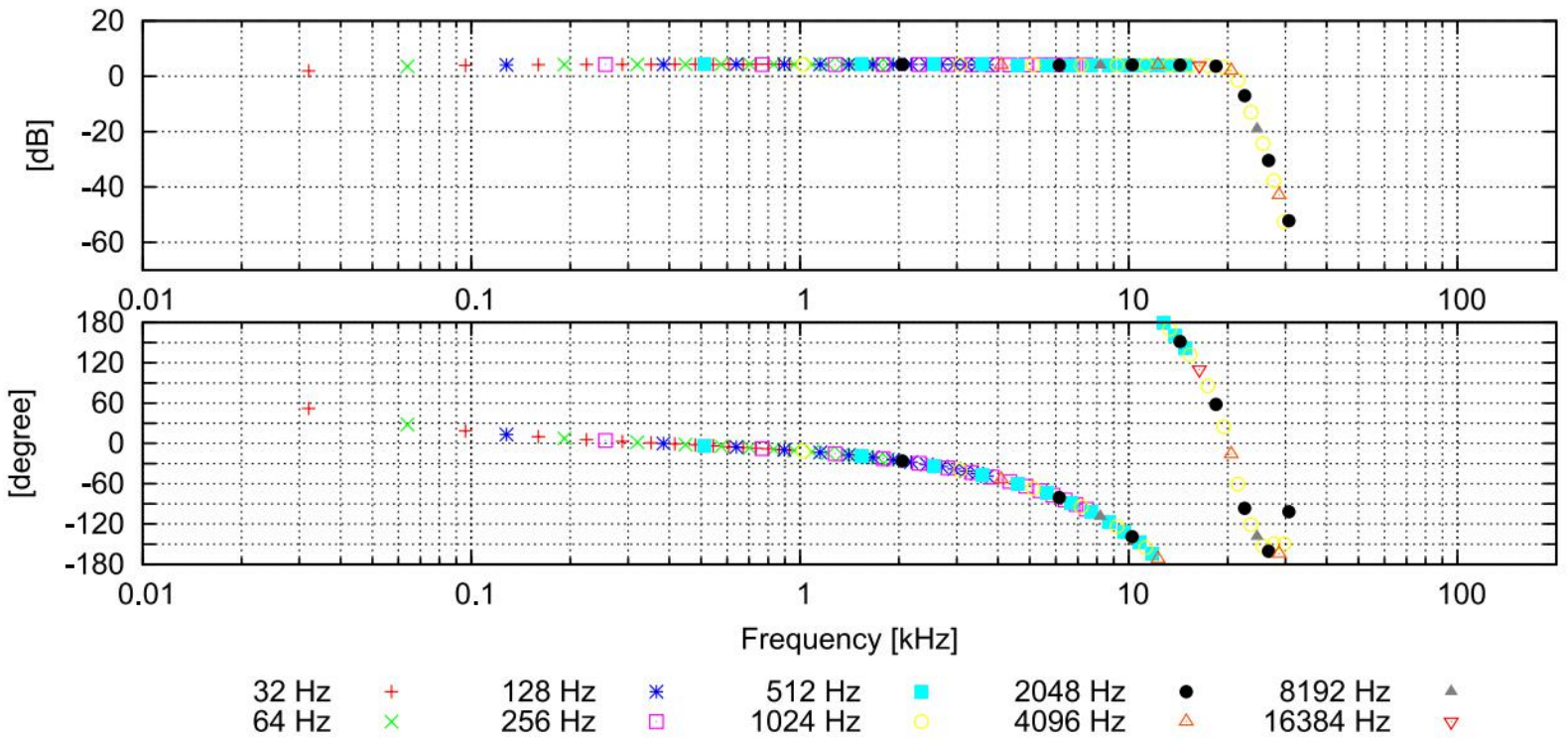


Fig. 13 A sample result of the SWCAL function obtained on the ground

Calibration of electric filed measurement

$$Z_T(f) = [\{(Z_A + Z_W) \,||\, Z_S \,||\, Z_C\} + Z_D] \,||\, Z_I$$

How could we do ?

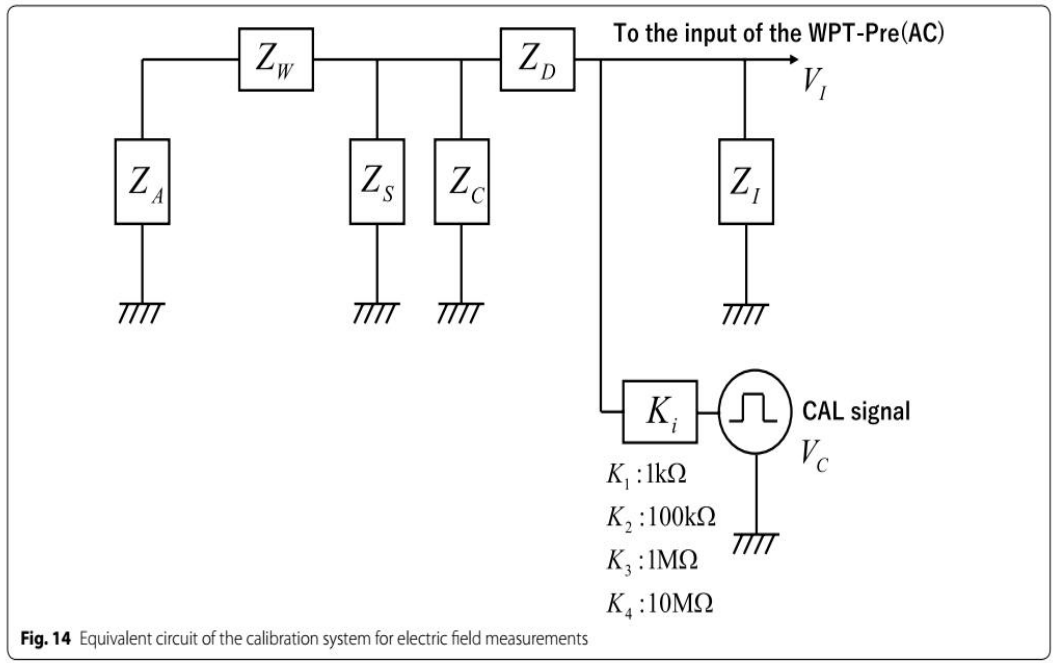


Fig. 14 Equivalent circuit of the calibration system for electric field measurements

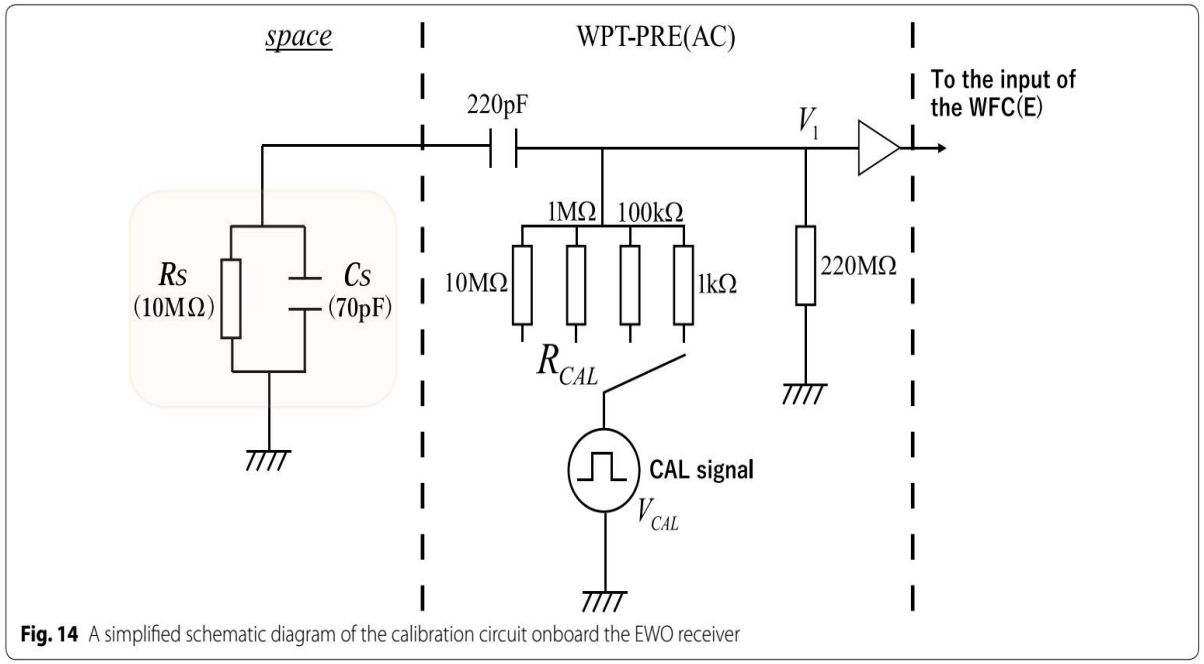


Fig. 14 A simplified schematic diagram of the calibration circuit onboard the EWO receiver

when RCAL is selected to 1 k ,We can measure the end-to-end frequency response of the WFC receiver .

Calibration of electric filed measurement

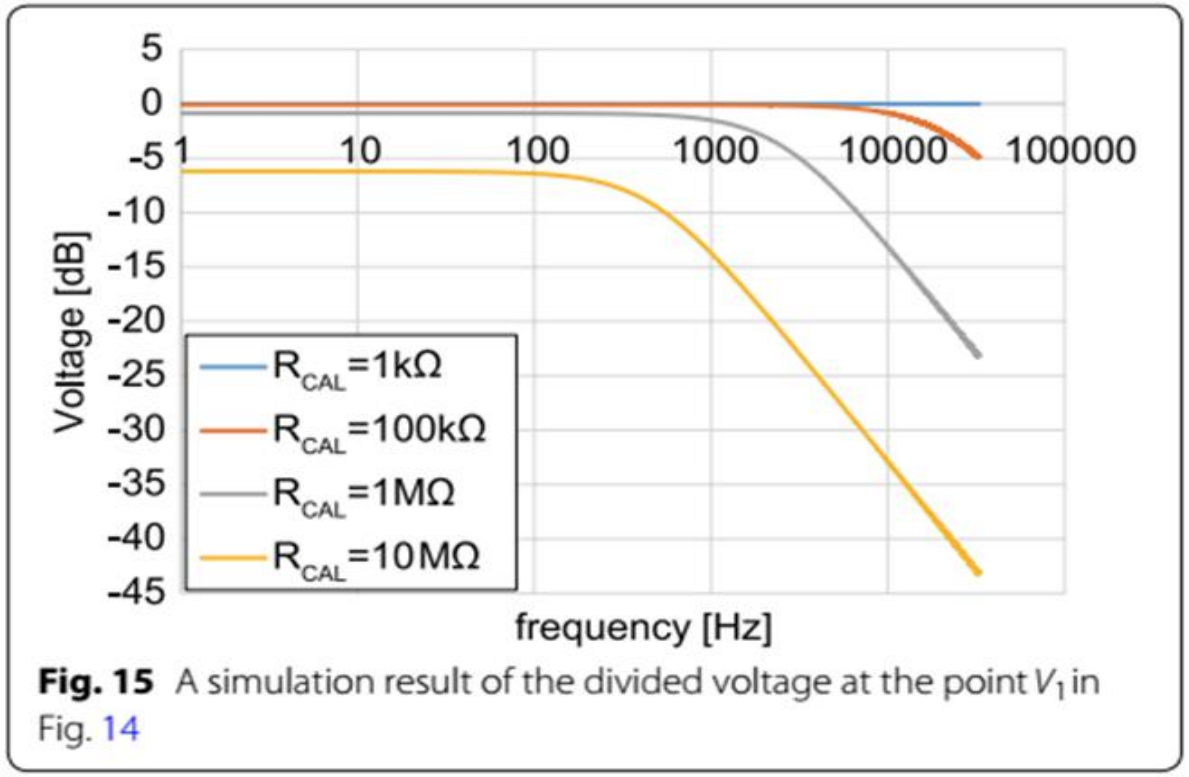


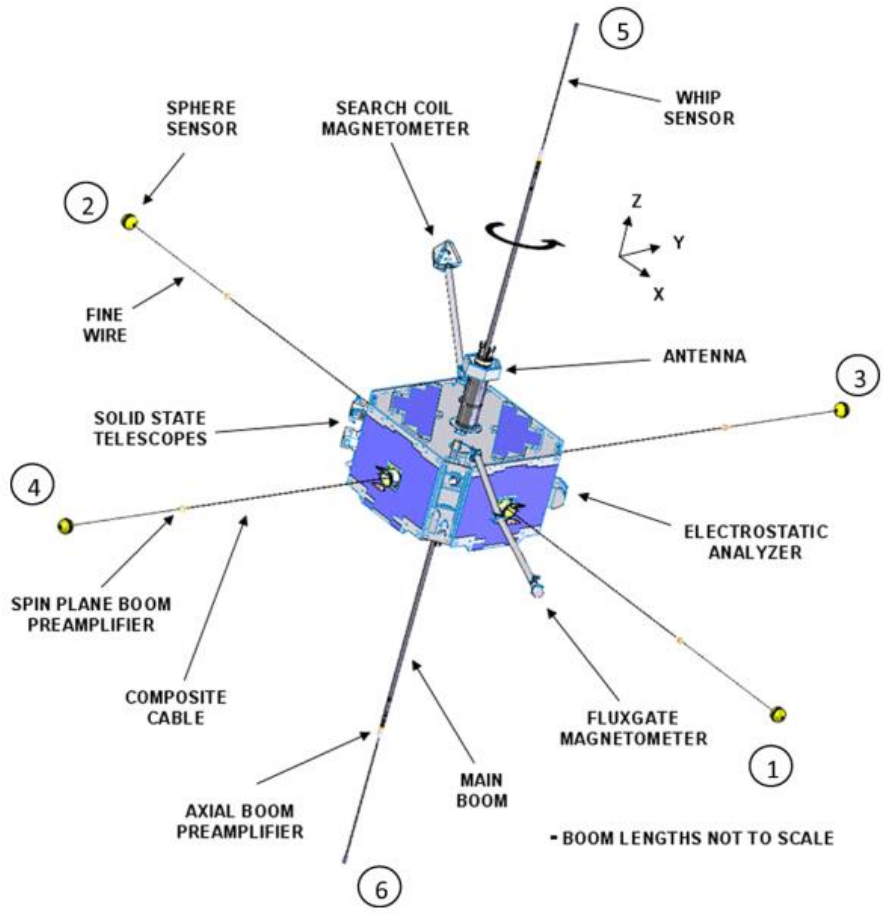
Fig. 15 A simulation result of the divided voltage at the point V_1 in Fig. 14

- when *K* is much smaller, the calculated $G_{WFC}(f)$ is equivalent to the end-to-end transfer function.
- Other impedances are used for deriving the antenna impedance Z_A from Z_T.

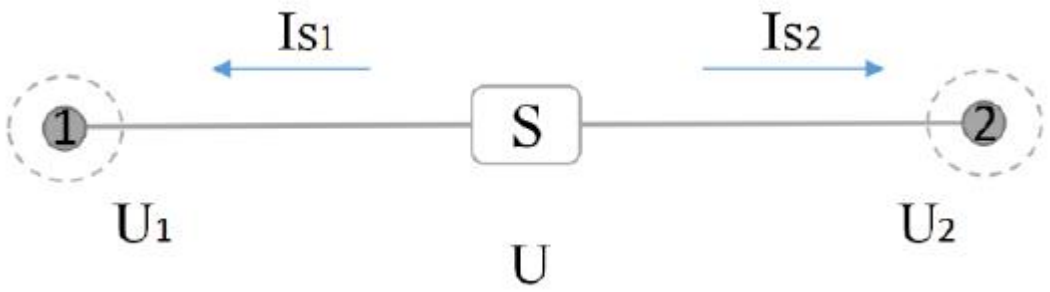
$$k \ll z_T \rightarrow \text{input} = \text{output}$$

$$k_1, k_2, k_3 \ldots \rightarrow \text{output1}, \text{output2}, \text{output3} \ldots \rightarrow Z_T \rightarrow Z_A$$

Calibration of electric filed measurement



[J.W. Bonnell,et al 2008] THEMIS



$$E = (U_1 - U_2)/L$$

$$\boldsymbol{E} = \frac{\boldsymbol{U}_1 - \boldsymbol{U}_2}{L} - \boldsymbol{V} \times \boldsymbol{B}$$

$\boldsymbol{U_1}, \boldsymbol{U_2}$ are the probe's potential.

$\boldsymbol{L}$ is two probes center distance.

$\boldsymbol{V}$ is the Machine speed.

$\boldsymbol{B}$ is the earth's magnetic field.

$\boldsymbol{E}$ is electric field for the space.

Calibration of electric filed measurement

calibration factors and boom shorting factors : due to current systems, pressure gradients, flow shears.

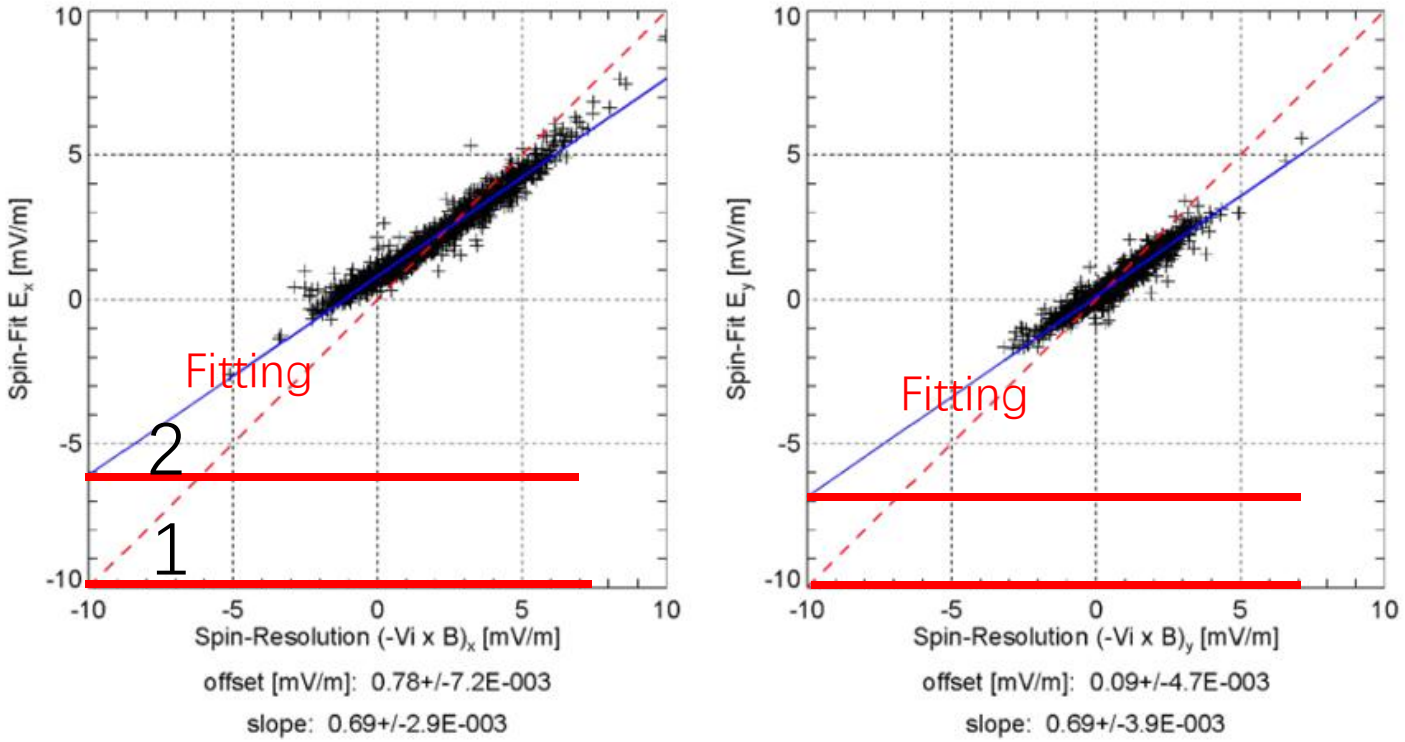


Fig. 21 Correlation analysis between EFI, iESA, and FGM data in the magnetosheath

Conditions :the electric, magnetic, and plasma flow fields are uniform and quasi-static, and the fluids themselves are collisionless, then the fields and flows are related by the standard ideal MHD.

$$\mathbf{E} = -\mathbf{V}_i \times \mathbf{B}$$

$$\boldsymbol{E_{EFI}} = -\boldsymbol{V}_{\mathrm{i}_{\boldsymbol{ESA}}} \times B_{FGM}$$

[Mozer et al. 2008]

Calibration of electric filed measurement

analytical function: Juno

Calibrations were primarily performed by applying input signals at known amplitudes and frequencies, and recording the output of the instrument. The same as Arase satellite

linear dipole antenna

There are three aspects:

1. the effective length of the antenna.

$$E = V/L_{eff}$$

2. voltage divider effect (antenna capacitance).

$$L' = L_{eff} C_A/(C_A + C_b)$$

3. antenna as a function of frequency.

W.S. Kurth et al 2017

Calibration of electric filed measurement

Table 9 In-flight calibration methods

Calibrated item	Comparator	Method	Frequency
AFG/DFG orthogonality	None	Spin plane quadrature, Spin-tone removal	Every orbit
AFG/DFG gains and offsets	Observatory AFG/DFG	Inter-observatory comparison	Monthly, or as needed
AFG/DFG gains	Spin-plane reference phase	Perigee pass analysis	Initial, quarterly or higher phase 1, 2
FG offsets	None	Variance analysis, Solar Wind	Yearly, as available
FG spin-axis offsets	EDI	Direction, TOF comparison	Weekly
SCM gains	AFG, DFG	Overlapping frequency band	Monthly
SCM gains, phase, offsets	None	Waveform analysis of cal signals	Daily
SDP, ADP gains	AFG, DFG	$-\mathbf{V}_{sc} \times \mathbf{B}$ perigee comparison	Initial, monthly phase 1, 2
SDP, ADP gains	FPI, HPCA	Solar Wind $-\mathbf{V} \times \mathbf{B}$ comparison	As available
SDP, ADP gains, offsets	EDI	Direct $\mathbf{E}_{perp}$ comparison	Continual, distinguishing different plasma regimes
SDP, ADP offsets	DFG, AFG	$\mathbf{E} \cdot \mathbf{B} = 0$ check	Quiet regions
SDP, ADP offsets	HPCA	$-\mathbf{V}_{O+} \times \mathbf{B}$ comparison	Lobe outflow regions
EDI MCP gains	None	Ambient response: MCP, pre-amp	Monthly

R.B. Torbert et al. MMS 2016

Compare with some others

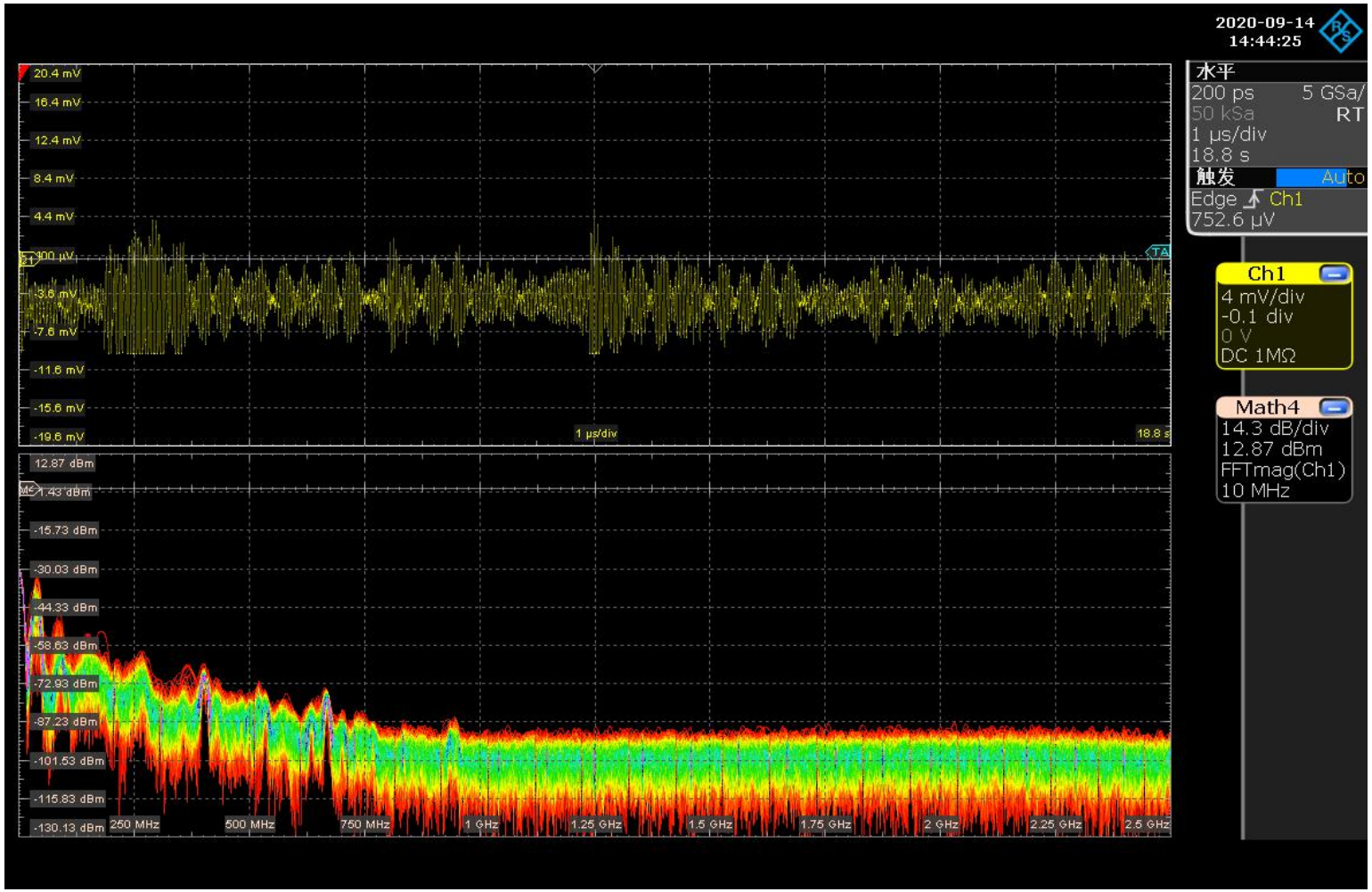
the same as THEMIS

conclusion

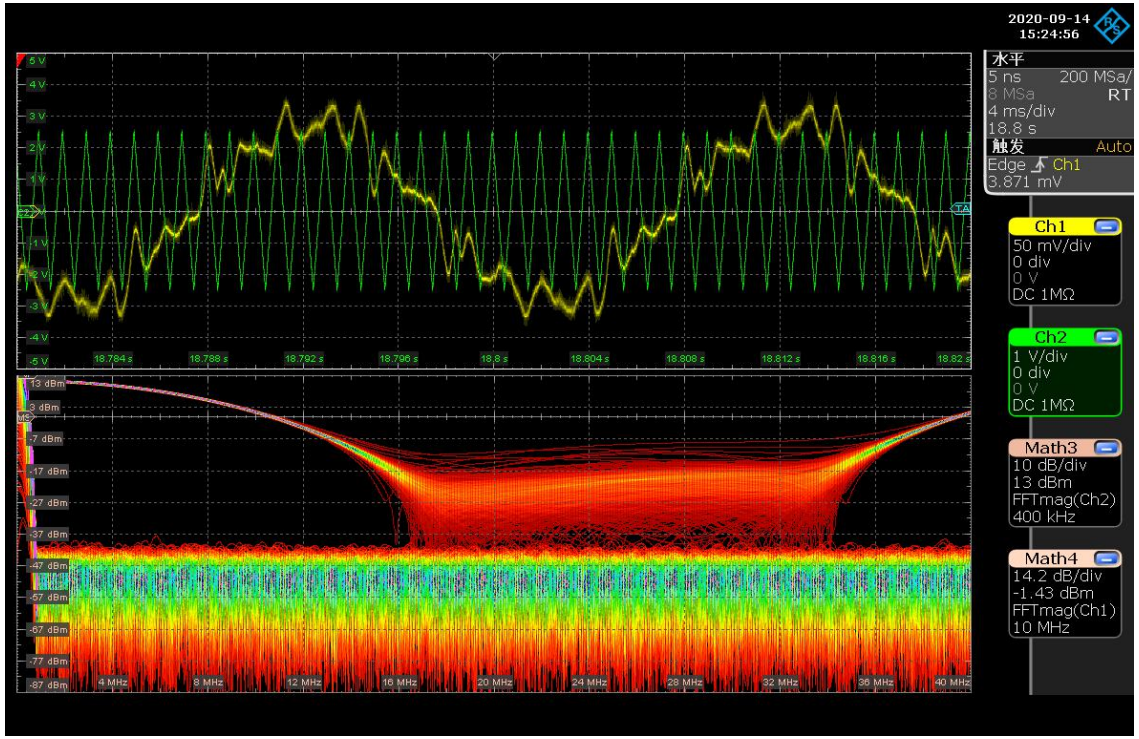
Doing Calibration have three methods

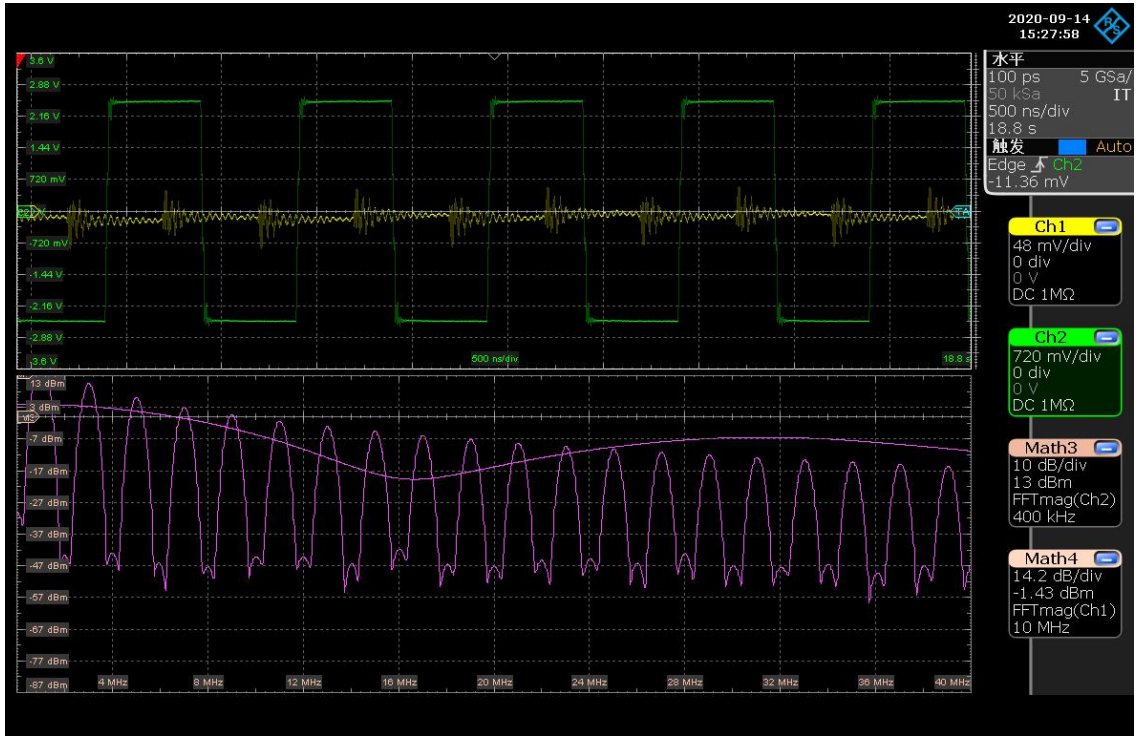
- Calculate the frequency response function
- Compare with other instruments
- Calculating system constant

experimental result

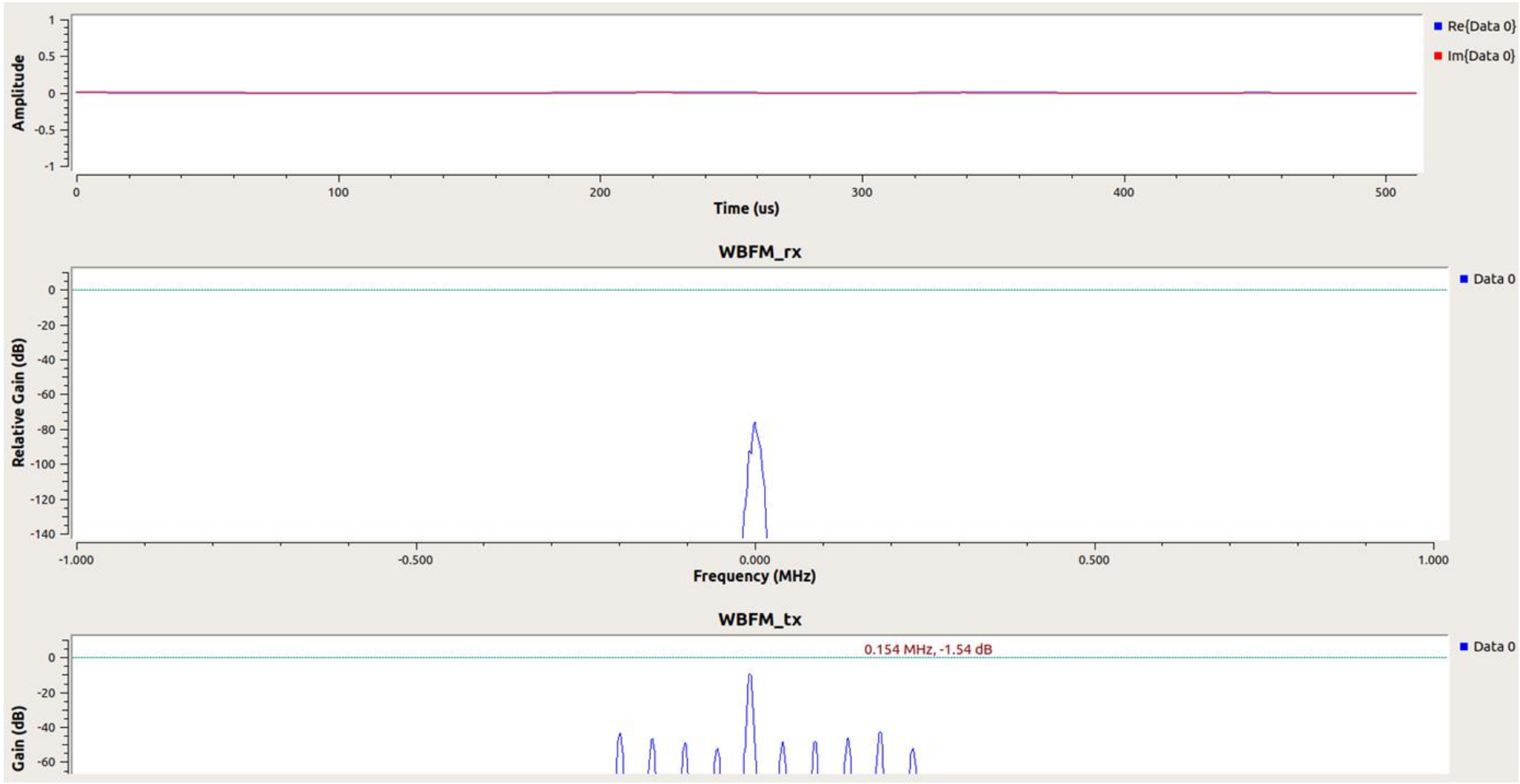


experimental result





experimental result



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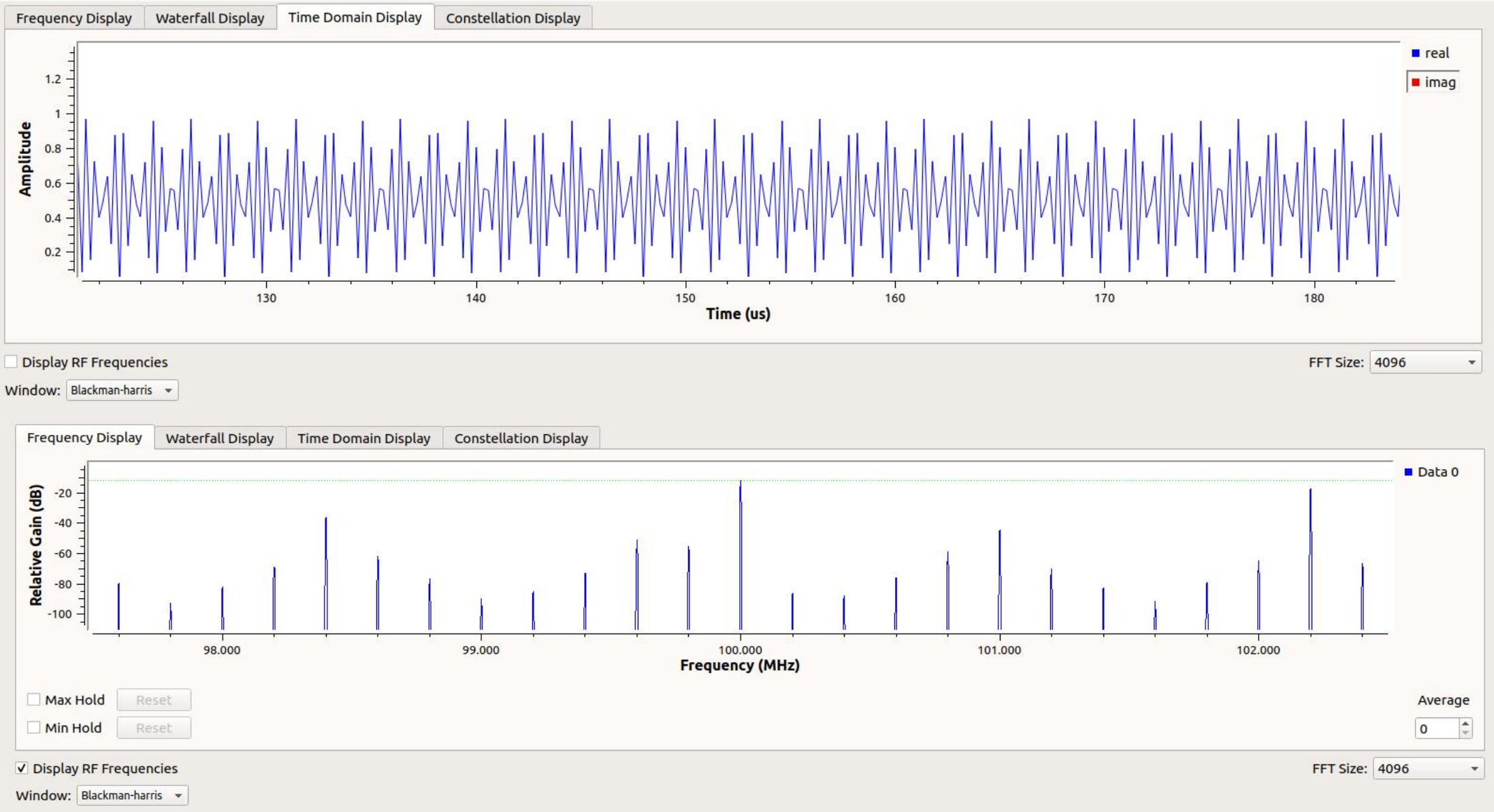

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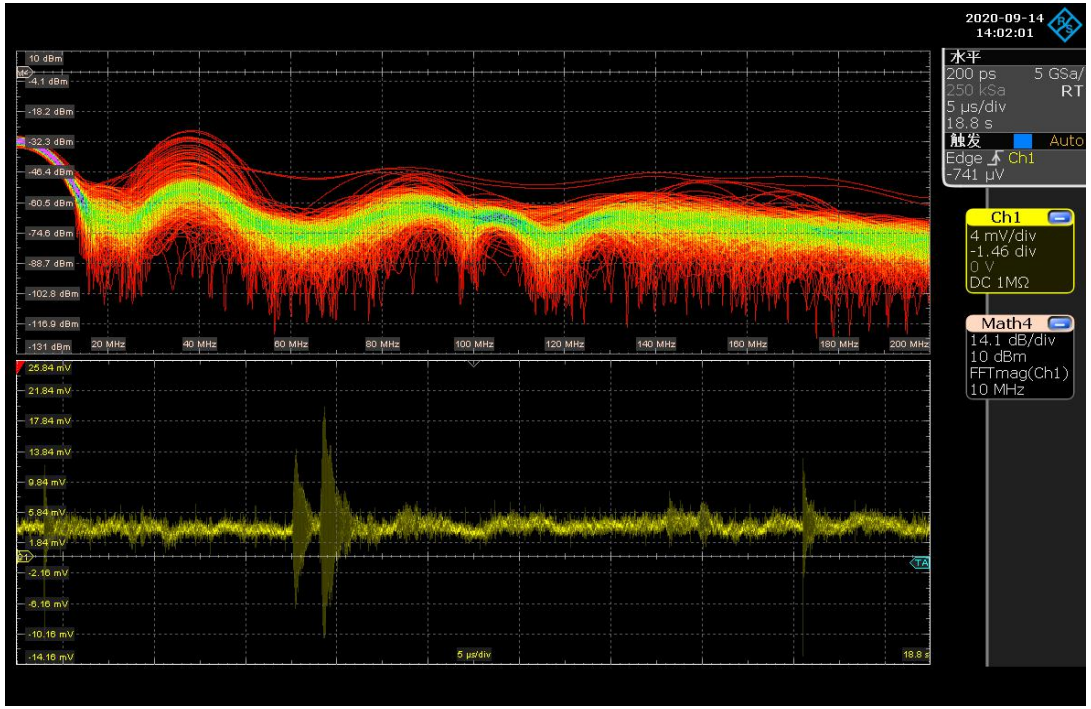

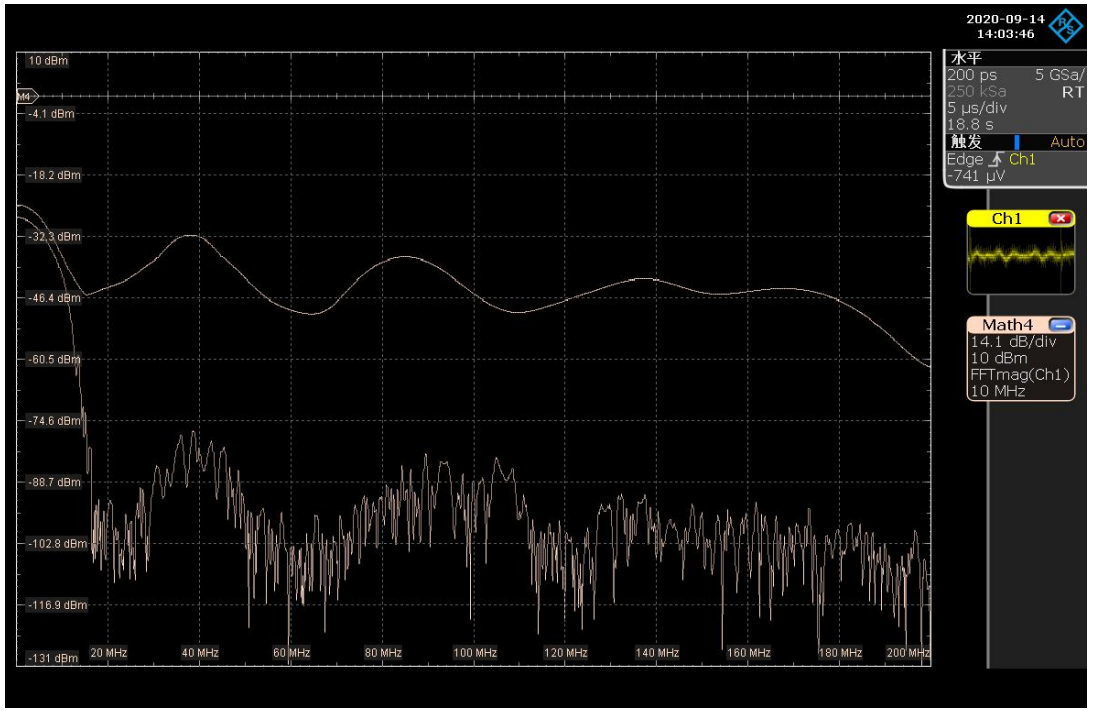

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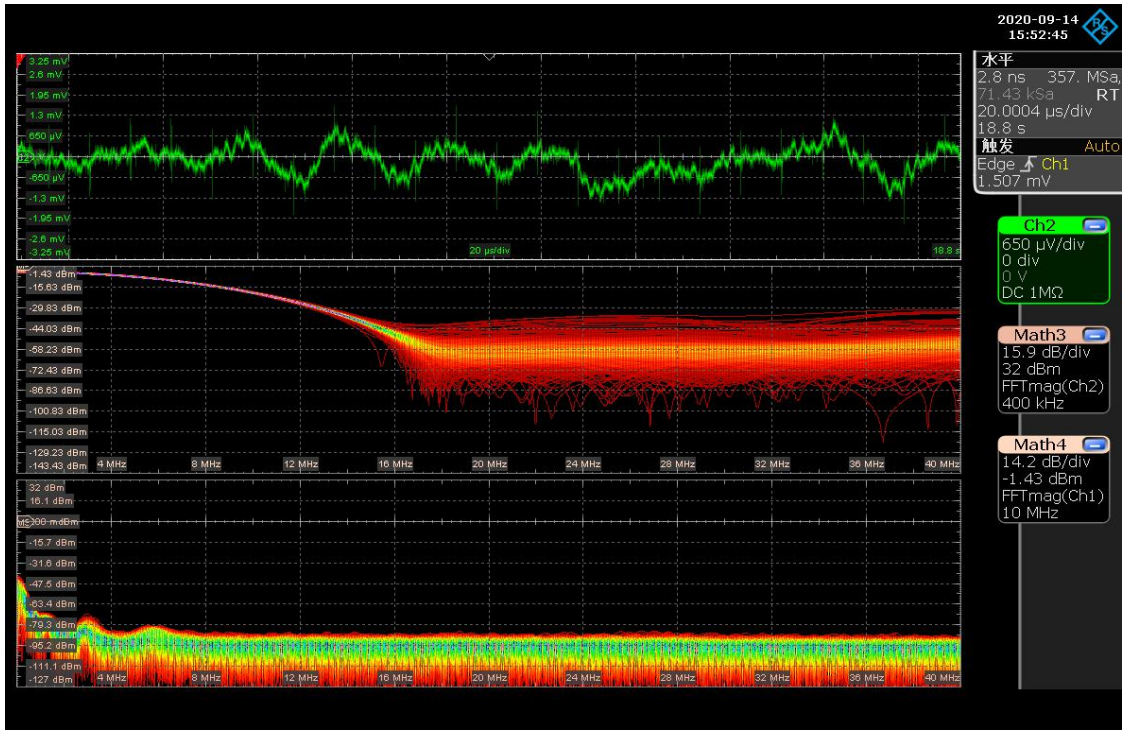

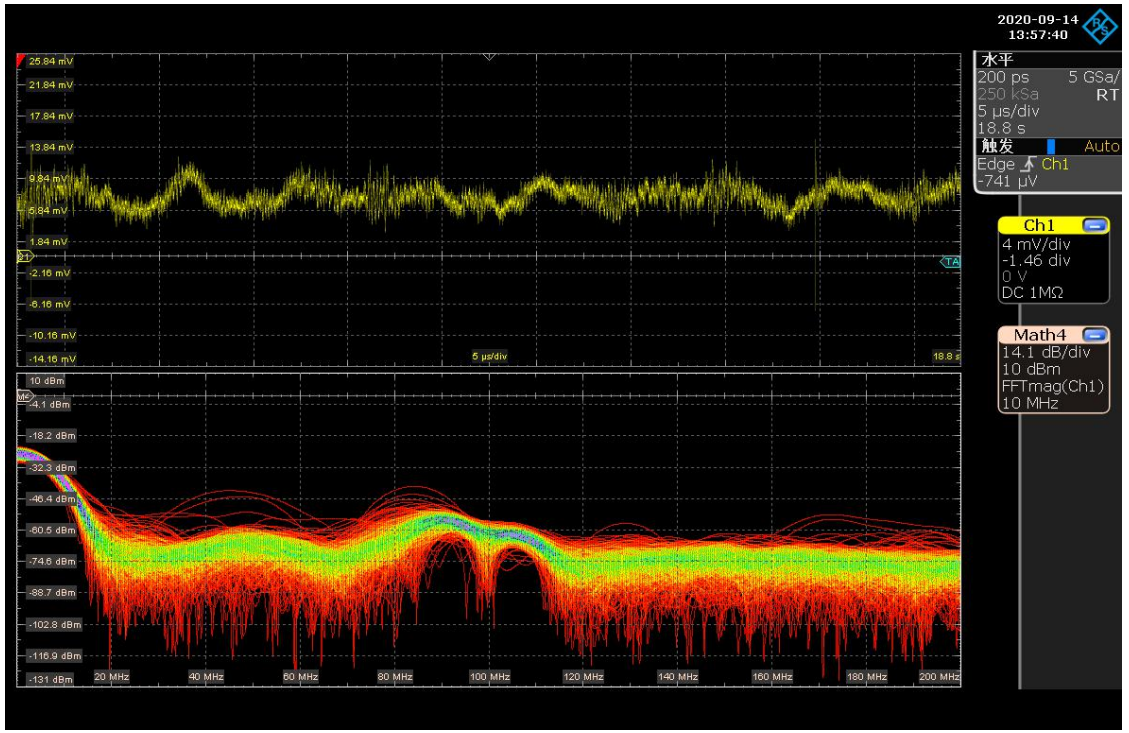

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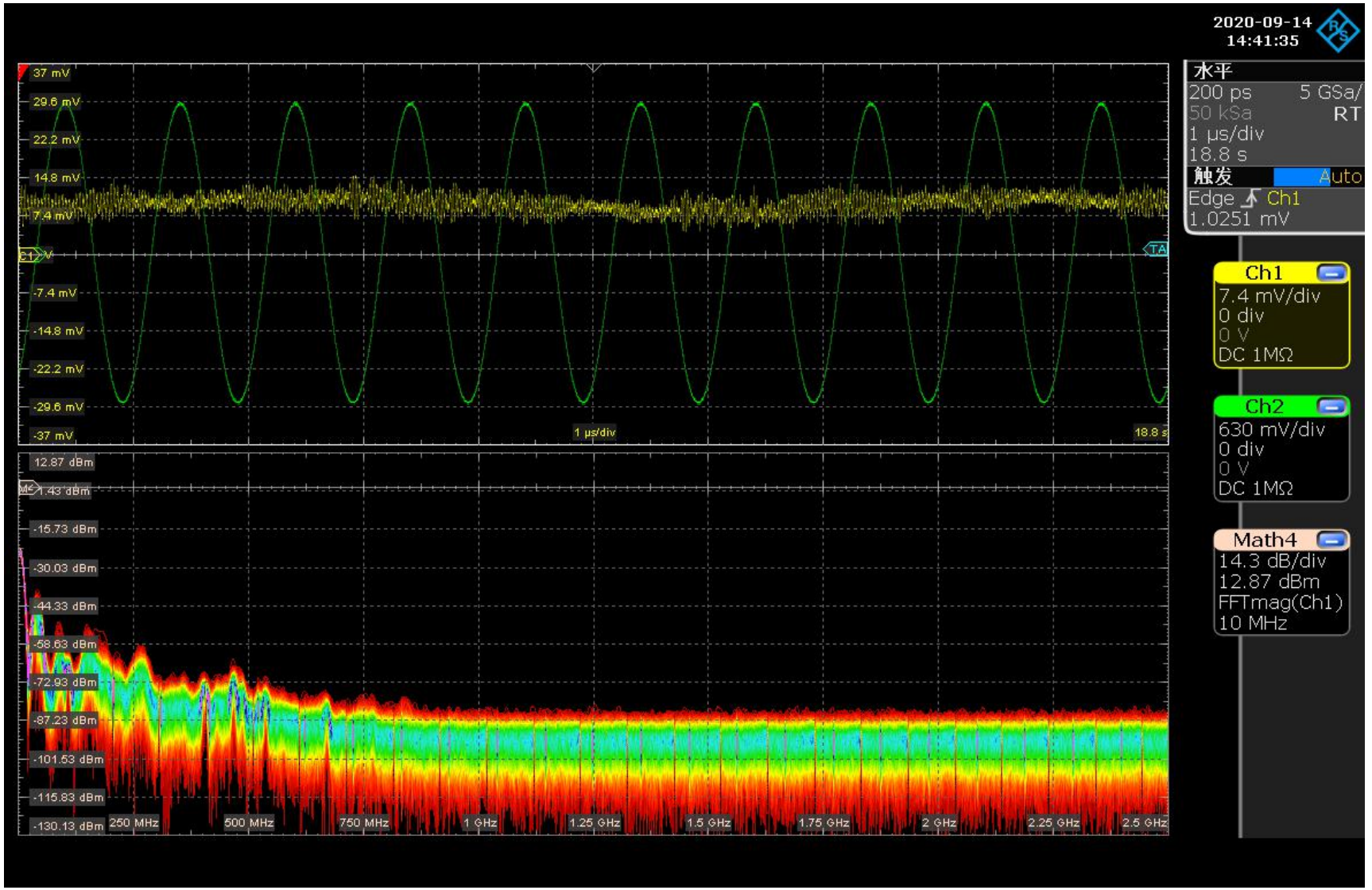

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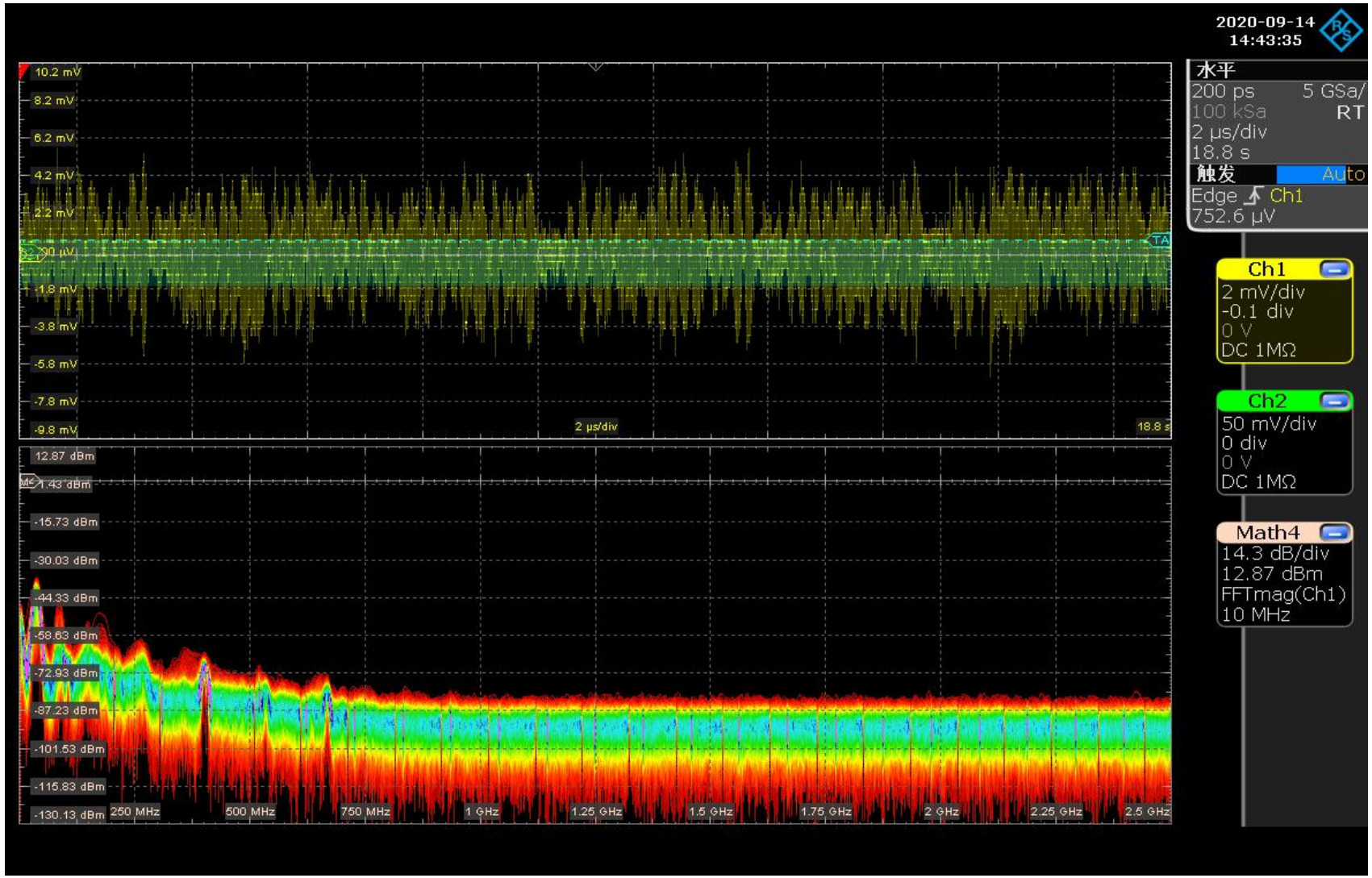

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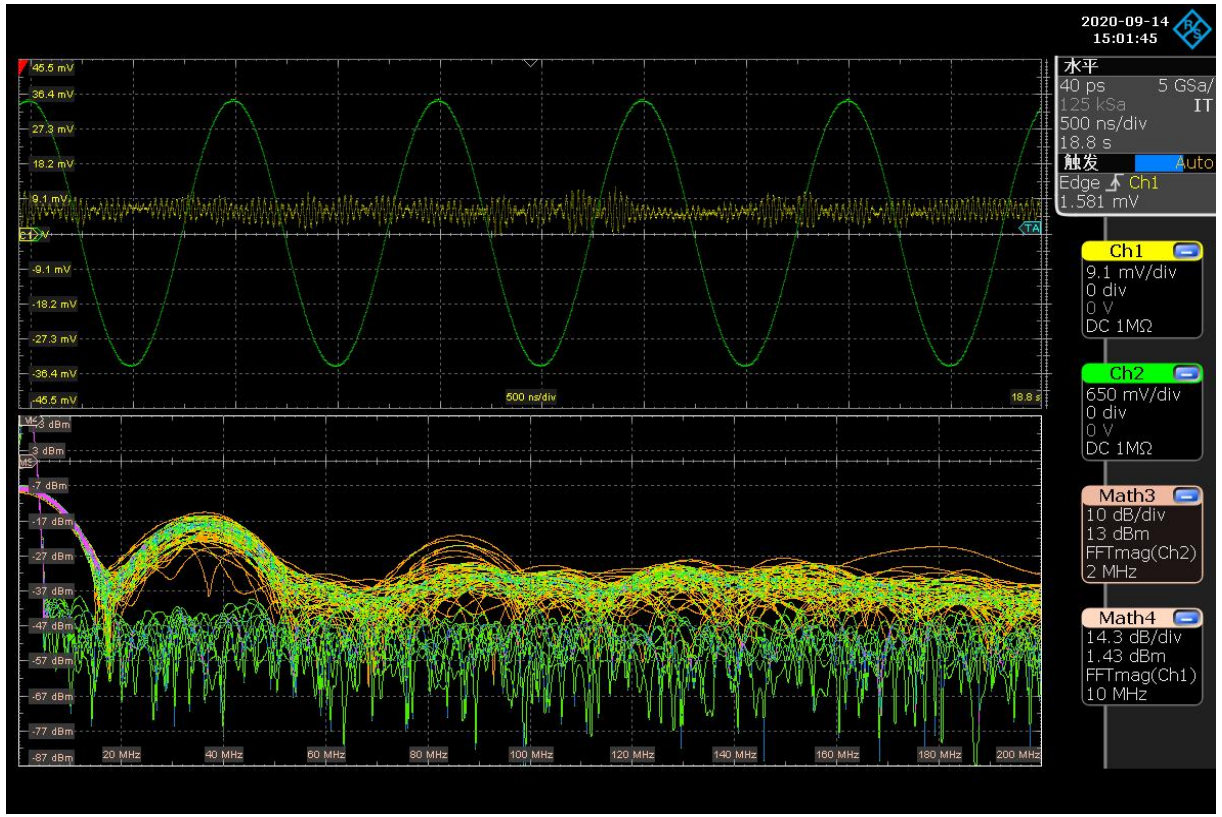

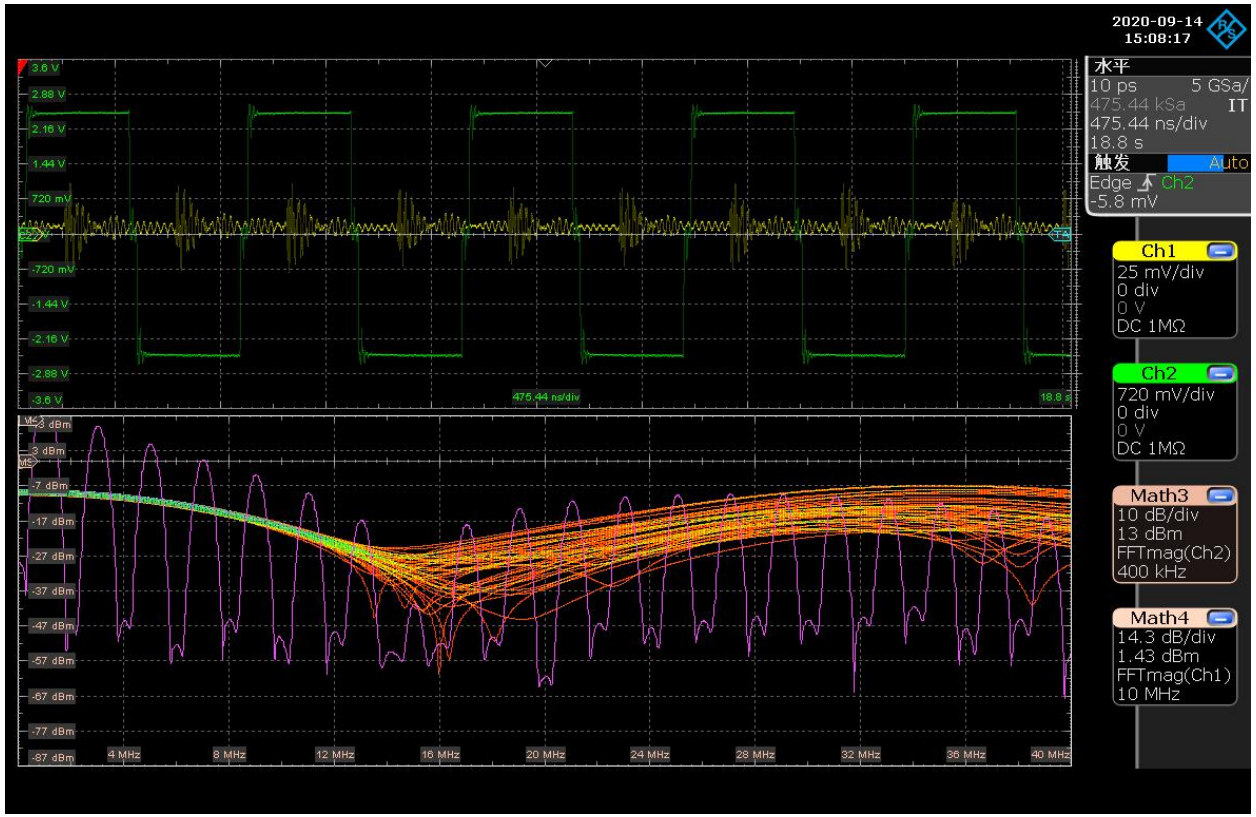

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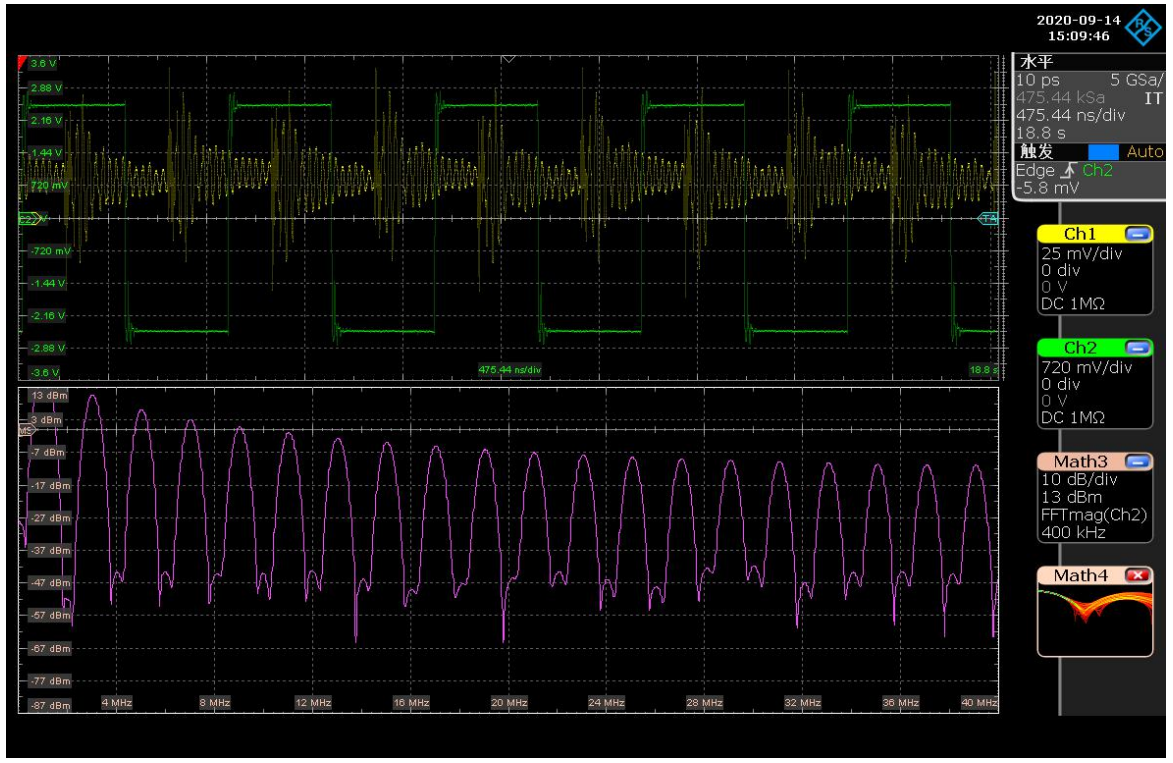

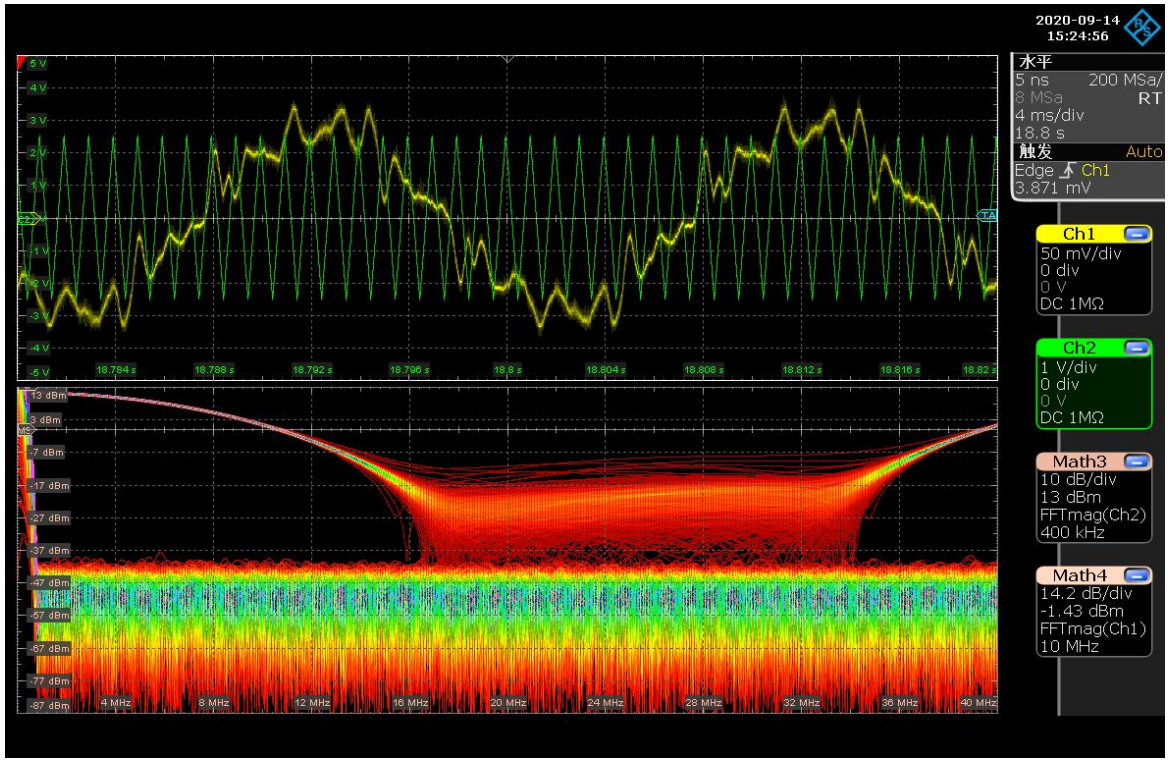

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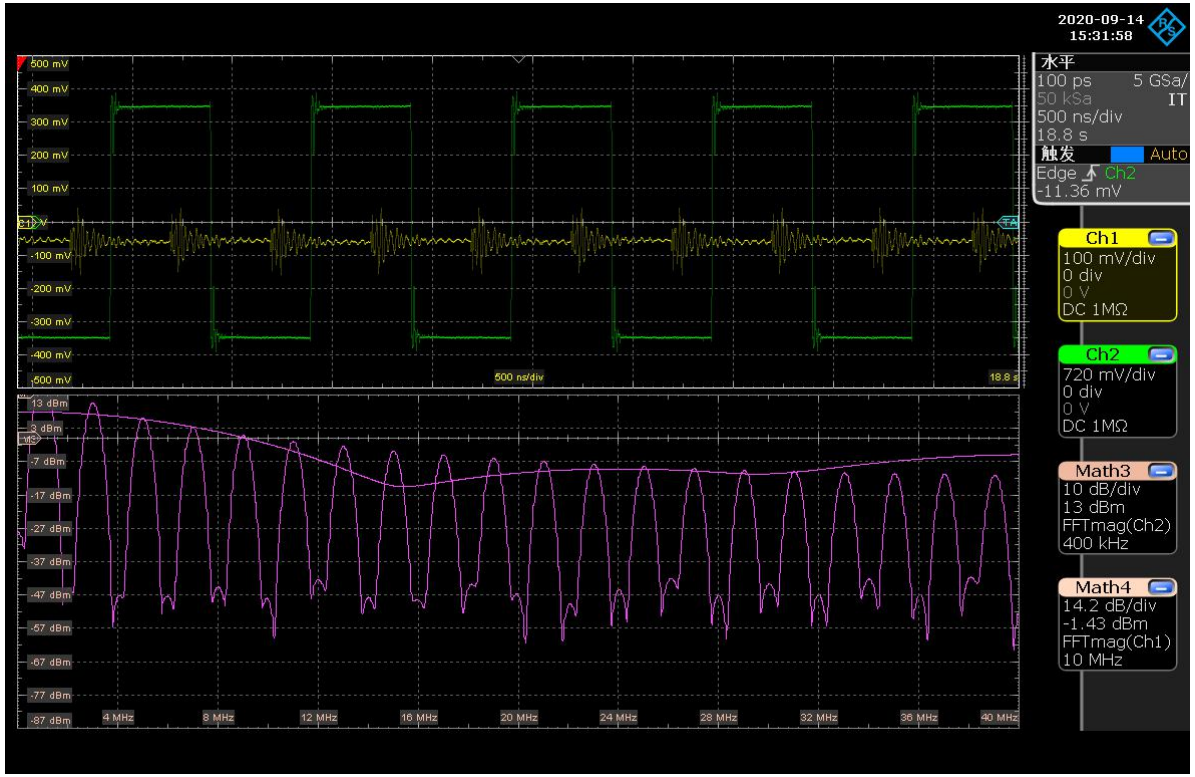

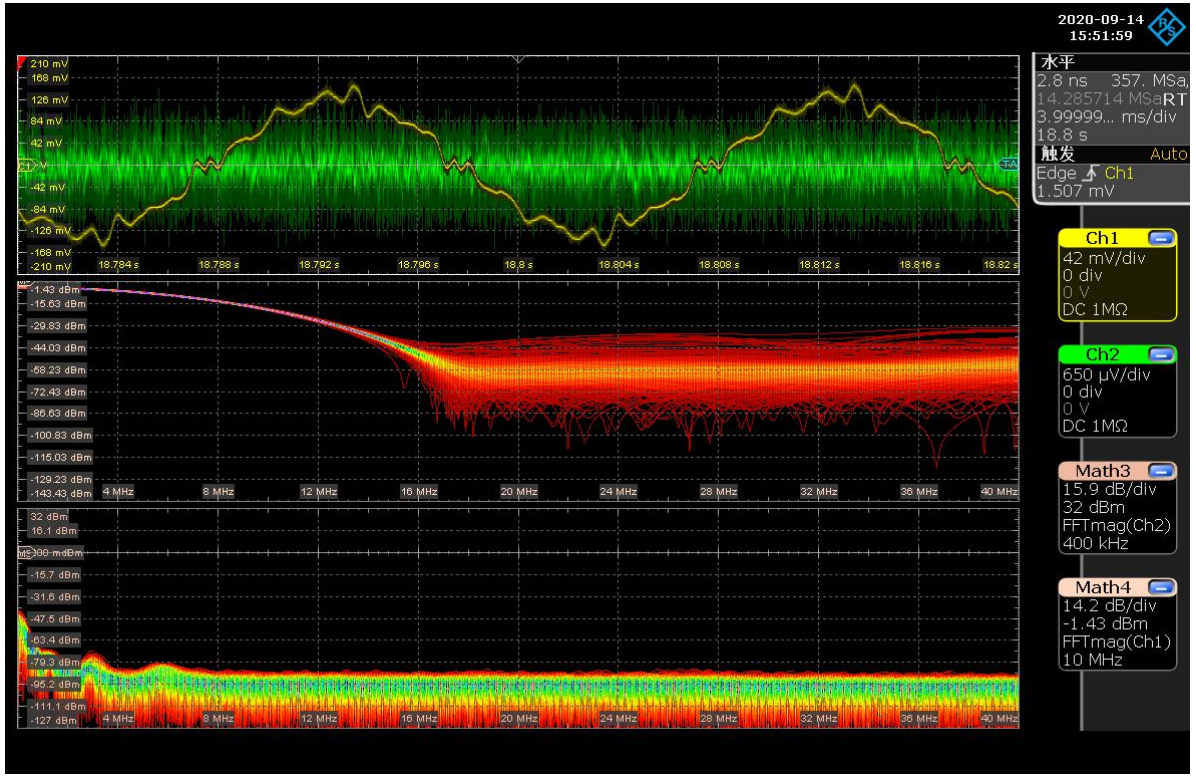

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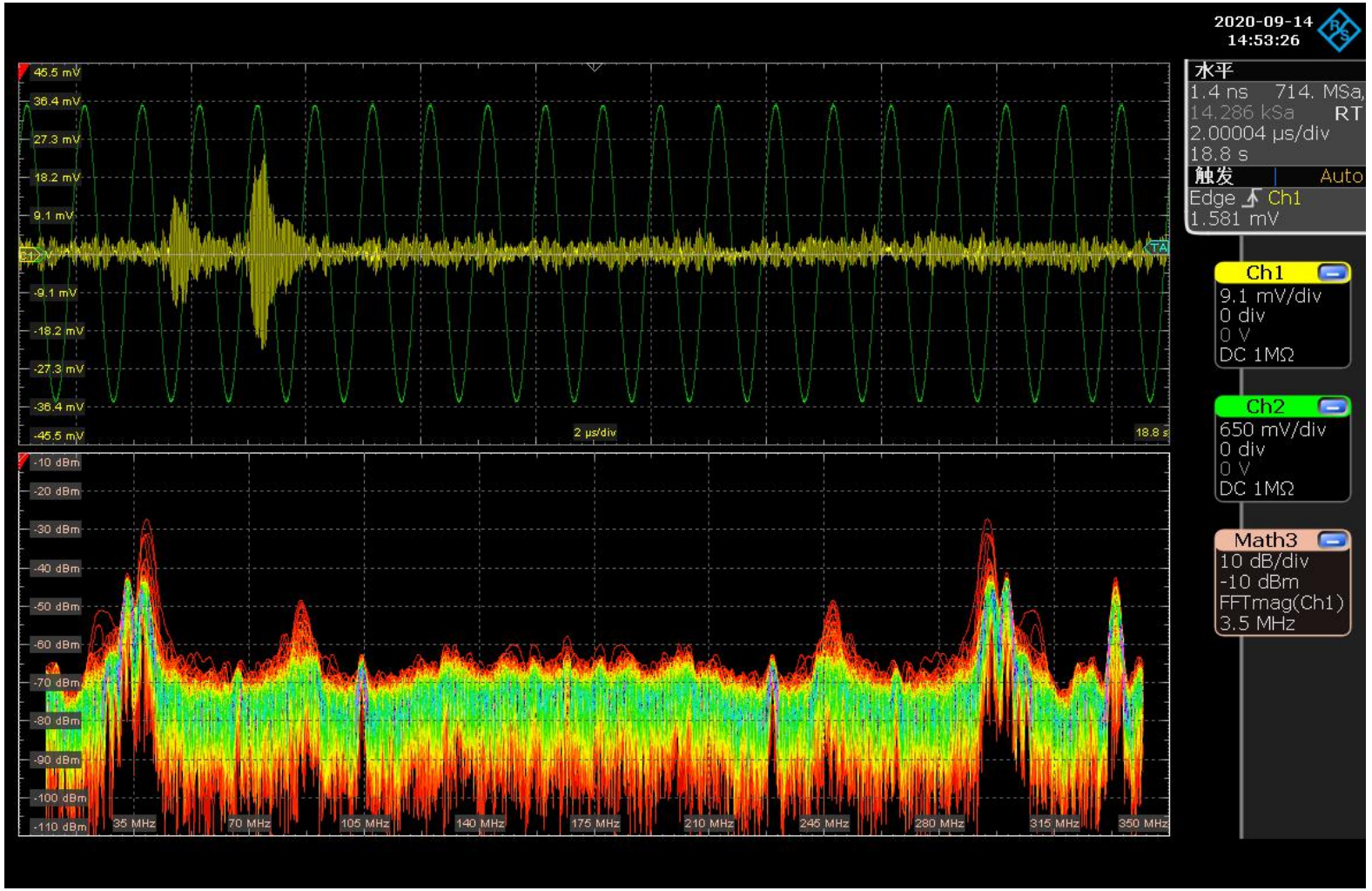

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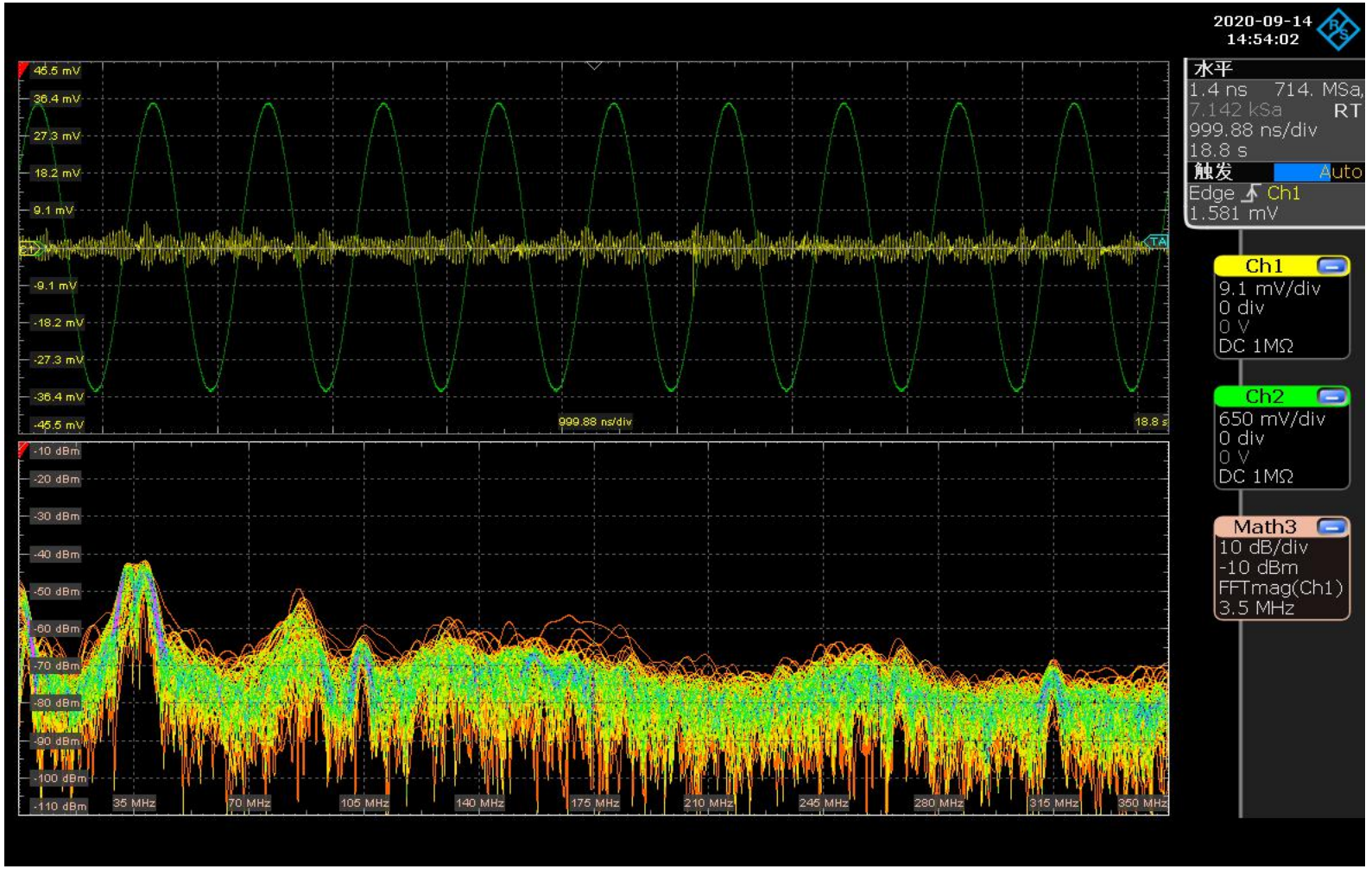

How can we find a wave